

THE MANUFACTURE OF ELECTRIC STEEL

BY

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and Steel Works Materials"*

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PREFACE

It has been evident for some time that a complete description of the manufacture of electric steel has been greatly needed. This need has been apparent throughout the steel industry. Although the men directly connected with the manufacture of special steels are thoroughly conversant with the electric process and its advantages and disadvantages, those in the steel industry outside of this one field have had very little opportunity to become familiar with it.

This need has been greatly felt in the colleges and universities. The young metallurgist has no opportunity at present to become familiar with electric furnace operation and with the practical side of electric steel making. Present texts on ferrous metallurgy can, of course, treat this branch of the industry but superficially. Again, the electric furnace melter, unless he has worked in several shops, has not become acquainted with all phases of furnace practice. There is no doubt but that a volume which discusses all branches of electric steel making, treating both acid and basic processes and the chemical reactions involved, would be of great value to the practical man on the furnace.

There are several excellent texts that take up electric furnaces from the standpoint of their electrical, mechanical and thermal efficiency but not one that describes electric furnace operation and the making of a heat of steel. Current literature on electric steel manufacture is exceedingly scant when compared with the literature on the other phases of ferrous metallurgy; the blast furnace, Bessemer converter or basic open hearth for example.

In the present volume the author has endeavored to fill the existing need by discussing fully the manufacture of electric steel, starting with the scrap and ending with the teeming of the ingots. After the heat is poured and the ingots stripped the furnaceman's duties are ended. If he has delivered a first class ingot to the rolling mill or forge shop he can rest content knowing that his is at least 90 per cent of the effort necessary to the manufacture of a perfect product.

In writing the present volume the various electric furnaces have been passed over with but brief mention. Even in describ-

ing the Heroult the construction and many of the electrical details have been slighted, to dwell on such practical considerations as power supply, electrodes, and lining, bottom and roof; details that are of utmost importance to the metallurgist and to the man on the furnace.

In the whole work the author has held to the opinion that high quality is the most essential consideration in electric steel manufacture. His descriptions of melting processes and his conclusions drawn from these descriptions have all been based on this essential. Never before in the history of the ferro-metallurgical industries has quality been so great a desideratum as in the past 5 or 10 years. The future expansion of the electric steel industry will be due to the fact that it can produce this high quality, for it can hardly hope to compete—at present, at least—with the Bessemer or basic open hearth in cost and tonnage.

The author believes that his descriptions of melting operations cover the best accepted practice in both basic and acid processes. He has tried to keep his language simple; sufficiently so that he may be thoroughly understood by the man who operates the furnace—the melter and the first and second helpers. In order to keep the language simple and easily understood, he has often reverted to the colloquial, oftentimes ungrammatical, but very expressive terms used by the furnace crew. For the benefit of the college student or young metallurgist he has made an effort to define such terms or expressions that would not be easily understood by the man outside the melt-shop. If he has failed in any way or if any expression seems obscure to the reader the author will appreciate it if it is brought to his attention so that it may be corrected.

It has been the aim, in writing this book, to refrain as much as possible from the expression of a personal opinion about furnace practice, although in one instance where the Austrian fiber-producing practice is discussed, the writer has taken sharp issue and expressed himself rather plainly. A published personal opinion is valuable only as it incites further discussion and if it results in clearing up a disputed point it is valuable whether right or wrong, and consequently is worth the space given to it.

The writer will probably be accused by many readers of over-enthusiasm. In this he begs indulgence. He firmly believes that the electric process, because of its deoxidation features, is the only possible and practical process for the production of high

grade steel in tonnage lots and he believes that the only thing preventing its more rapid advance is the cost of power and the hesitancy of the purchaser to pay a little additional for a much superior metal. Cheaper electric power is a question of the future, probably of the near future. Users of high grade steel are gradually realizing that the first cost is often a comparatively unimportant item. Consequently he is enthusiastic enough to prophesy electric steel rails and structural material within the next two decades.

In the first book to describe a new ferro-metallurgical process, especially a process as young as electric steel making there are likely to be some omissions. The author will thank readers who call his attention to any that are obvious.

This opportunity is taken to express sincere appreciation and thanks to the following firms and individuals who so kindly furnished suitable material for the illustrations: Bureau of Mines for Figs. 5 and 28; Hess Steel Corporation for Figs. 7, 13 and 43; Inspector of Ordnance in Charge, U. S. Naval Ordnance Plant for Figs. 18, 19, 32, 33, 34 and 44; Acheson Graphite Co. for Figs. 6 and 25; National Carbon Co. for Figs. 8, 9 and 10; General Electric Co. for Fig. 11; Electric Furnace Construction Co. for Figs. 12, 20 and 21; McGraw-Hill Book Co. and Prof. Alfred Stansfield for Fig. 2; Iron Age for Figs. 15, 16 and 17; Pittsburg Electric Furnace Corporation for Figs. 23 and 24; C. H. Vom Baur for Fig. 26; Greene Electric Furnace Co. for Fig. 27; Chemical and Metallurgical Engineering for Fig. 29; Youngstown Sheet and Tube for Fig. 38. and Penn Mold and Machine Co. for Fig. 39.

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THE MANUFACTURE OF ELECTRIC STEEL

CHAPTER I

ELECTRIC STEEL, ITS PAST, PRESENT AND FUTURE

Electric Steel, Its Past—Electric Steel, at Present—the Future of Electric Steel.

The electric process for the manufacture of steel is the infant of the iron and steel industry; and a lusty infant it has become in the past 10 years. Little more than 20 years ago the manufacture of steel by means of the electric furnace was still in the embryonic stage but now more than 1,000 electric furnaces are in operation in America and Europe, more than a third, 406 to be exact, in this country. In the past 10 years, the advance of electric steel has been nothing short of phenomenal, the production of this grade increasing from 52,141 tons in 1910 to 502,152 tons in 1920 or 900 per cent (Table I). The year 1921 is not taken into account as it was a year of depression. For that matter, 1920 was abnormally prosperous. It is probable, though, that 500,000 tons will represent very nearly the average production in the next 3 or 4 years. The data on the castings production is especially illuminating; in this branch of electric steel manufacture the electric furnace has made rapid strides. In fact, in 1921, the production of castings exceeded the ingots. This, however, may not be representative as the depression was felt more severely by ingot producing plants.

Nearly all of the advance in electric steel has occurred in the past 10 years. In 1912 there were only about 125 electric furnaces in the world, less than 20 of these in America. At present,¹ there are nearly 1,200 in operation; one third of them in this country and about half in this country and Canada. The recognized ability of the electric process to produce alloy and tool

¹ *Iron Age*, Jan. 4, 1923.

steel ingots and the superiority of the process in the manufacture of castings has made this advance possible. The American steel maker should be complimented on the foresight shown in making this country the foremost producer of electric steel in the world.

TABLE I.—ELECTRIC STEEL PRODUCTION

Year	Ingots	Castings	Total
1909	13,456	306	13,672
1910	50,821	1,320	52,141
1911	27,227	1,878	29,105
1912	14,147	4,162	18,309
1913	20,973	9,207	30,180
1914	15,458	8,551	24,009
1915	46,348	23,064	69,142
1916	126,048	42,870	168,918
1917	239,632	64,911	304,543
1918	403,068	108,296	511,364
1919	272,942	111,510	384,452
1920	346,956	155,196	502,152
1921	84,404	85,095	169,499

Statistics furnished by *Iron Age*.

Of this production the Heroult led with 179 furnaces or more than a third. Most of the Heroult installations are 6 tons or larger so it is safe to estimate that this furnace produces 50 per cent of the total electric steel made in this country and more than 75 per cent of the ingot production. The rest is made in a few furnaces of the direct arc type. These we will reserve for later discussion.

ELECTRIC STEEL, ITS PAST

First Attempts at Electric Steel Melting.—Although the principle of heating by electricity was discovered early in the nineteenth century, William von Siemens, in 1878 and 1879, was the first to apply the electric current to melting iron. His equipment was essentially a small crucible containing the charge into which were introduced two carbon electrodes. Siemens' invention is particularly interesting as he was the first to perfect devices for the automatic regulation of the arc and because most modern arc furnaces are adaptations of his original design. After

the experiments of Siemens the advance of electric steel melting was halted. Nothing more was accomplished until the year 1892 when De Laval patented his furnace for refining iron. This invention although impractical is important as the first attempt to melt and refine iron by resistance.

During these years the steel industry refused to take the electric furnace seriously; first, because of the development of the basic open hearth and second, because of the prohibitive cost of power. Naturally inventors turned to other fields and in the years 1888 to 1894 Heroult successfully employed the electric current in the manufacture of aluminum, calcium carbide and ferro-alloys.

First Practical Steel-making Furnaces.—With the development of water power in Europe and cheaper steam power in this country electric steel-melting possibilities were again brought to the fore. In 1898 Stassano took out a patent for "melting and refining liquid alloys of iron and of iron and carbon by the electric current." The present Stassano furnace shows but little improvement over the first design.

In 1900 Kjellin devised his induction furnace and placed one in operation at Gysinge, Sweden, and in the same year Heroult, whose furnace had been actively engaged for some time in the manufacture of aluminum, calcium carbide and ferro-alloys, made the necessary alterations for melting and refining steel. The electric furnace was introduced into this country soon after when the U. S. Steel Corp. secured the American rights to the Heroult furnace. Thus we see that three distinct types of electric steel-making furnaces appeared at about the same time, 1900; the Stassano using an indirect arc, the Heroult using a direct arc and the Kjellin, an induction furnace. It might be mentioned that the first induction furnace was patented by an American, Colby, in 1890. While important as the first application of the transformer principle to steel making, his furnace was never practical commercially.

Later Developments in Electric Furnaces.—The years 1900 to 1912 were very active ones in experimenting with the electric current as a means of producing steel. Girod brought out his furnace in 1906. In it, he used Heroult's original idea of a bottom electrode, but so changed that it was applicable to economic operation on either scrap or hot metal. In the same year the Röchling-Rodenhauser induction furnace, an improvement over the Kjellin, was put into operation. This furnace is

the only one using the transformer principle that has survived, and even it has limited applications and few installations.

In 1912 Rennerfelt perfected his arc furnace. It was a modification of the old Siemens crucible having two horizontal electrodes. In addition, it had a vertical electrode let down through the roof by which the arc from the horizontal electrodes could be deflected down on to the bath.

Other furnaces developed in this period are the Grönwall, an arc furnace with a conducting hearth, the Nathusius also of the direct arc, conducting-hearth type, and the Frick and Hiorth, both induction furnaces. Few of the earlier furnaces have survived.

Evolution of the Present Furnace.—The experimentation of the electro-metallurgists in the years 1900 to 1915 resulted in a restriction of the types of electric furnaces to four: The indirect arc, the direct arc with a non-conducting hearth, the direct arc with a conducting hearth and the induction. Because of local overheating and other disadvantages, the indirect arc furnace, the most important of which is the Stassano, has proved impractical in the United States. The Rennerfelt might be included in this class.¹ Likewise the many bad features connected with the operation of the induction furnace, notably its unsuitability for cold charges has made this type unpopular in America. Thus we have narrowed down to two types of furnaces, the direct arc with a non-conducting hearth of which the Heroult is the outstanding example, and the direct arc with a conducting hearth including the Girod and many recent furnaces. The discussion of these may be properly postponed until a later chapter.

ELECTRIC STEEL, AT PRESENT

The advance of the electric process for making steel is as we have seen nothing short of phenomenal. The electric furnace is unique in ferro-metallurgical processes, in that it will produce a high-grade material in tonnage lots. It is undoubtedly true, although not consistently accomplished at present, that the same quantity of steel, say 30 to 50 tons, delivered by the open hearth can be made in an electric furnace and in quality equal to the best product of the crucible pot. Does it not seem remark-

¹ The Rennerfelt has proved very successful in small sizes, under 3 tons.

able that, when power costs are lowered only slightly, steel can be made in the electric furnace at a cost not exceeding one quarter of a cent a pound more than ordinary open-hearth metal and of a grade that is 20 to 100 per cent better?

Advantages of the Electric Process.—The first great advantage of the electric process is flexibility. It can be successfully operated with cold charges or hot metal. It can be used for castings, for making pig iron synthetically, and for refining molten cupola iron. In the electric furnace, every metallurgical ideal can be met; the temperature can be controlled within a very few degrees, both oxidation and reduction can be carried to any point desired, and the two impurities always present in iron and steel, sulphur and phosphorus, can be eliminated down to a trace. The electric process is the only commercial steel-making operation that will oxidize thoroughly and later deoxidize completely, removing all of the sulphur at the same time. In view of these facts the electric furnace, as a commercial steel-making proposition, is probably less than 10 per cent developed; in other words its possibilities are apparently unlimited.

The second great advantage is quality. The process, by proper handling, produces steel equal in every respect to the best crucible steel. Compared with a steel made by the open-hearth or Bessemer process, electric steel has greater density, can be made free from blowholes, free from slag and occluded or absorbed gases, and is stronger, tougher and more ductile. From the standpoint of quality, one of the features of the electric process is the fact that the steel can be made in the furnace. All alloy additions are made directly to the bath;¹ no loss of alloys ever occurs. This results in a steel which is freer from segregation as all furnace additions have sufficient time allowed for their melting and thorough mixing.

In the electric furnace the heat, through the medium of the arc, is placed exactly where it is most necessary. Local overheating is thus prevented or largely minimized. Again, the electric furnace stands alone in the degree of heat obtainable. This facilitates refining and permits slag reactions to become completed in a very short time. The question of quality will be discussed fully in a later chapter.

Disadvantages of the Electric Process.—The outstanding disadvantage of the electric process is cost; although in the past 2

¹ A possible exception to this is in the case of uranium and zirconium.

or 3 years, cost is not a serious handicap and will be even less of a handicap as power resources become more completely developed and as economies of furnace operation are more thoroughly understood and practiced.

Aside from cost the only disadvantage of the electric furnace is its operation at present by men unfamiliar with its possibilities; men untrained in deoxidation and unaware of its ability to produce fine steels. When furnacemen become more thoroughly trained in electric furnace metallurgy and realize that the process does not fit into a position intermediate between the open hearth and the crucible, but occupies a place in steel production equal to the crucible pot, then good electric steel will be made. The author, after many years' experience in electric steel melting, will try to show in the pages that follow why the electric process ranks supreme as far as quality is concerned, and why 50-ton heats should be of a quality equal to 100-lb. crucible heats.

The rapid expansion of the electric process in the period 1913 to 1920 resulted in a condition which might have been expected and could have been avoided had the installers shown only a fraction of the caniness and shrewdness exhibited by most of them in adoptions of other metallurgical innovations.

Part of the trouble encountered in this period was due to the electric furnace builders who, by various methods of propaganda, instilled the idea into the steel industry that the electric furnace was a cure-all, a fool-proof process, one that would produce the finest steel from an inferior base and one that could be operated by ignorant and unintelligent labor. Nothing is farther from the truth. The successful operation of the electric furnace demands skilled labor of the highest order. The process of deoxidation is too little understood to permit an inferior base to be used. Perhaps when we are farther advanced, we will be able to charge "scrap iron, lathe turnings and tin cans" into a furnace and produce therefrom a heat of high-grade ball bearing steel. At present, however, it cannot be done.

Because the chemistry of the process was but little understood, because too much was expected of it, and because—this is most important—it is impossible to combine too much speed with high quality, a large percentage of the electric steel produced in the past 5 years has not been of the best quality; in fact, some of it has not been worthy of the name and electric steel has thereby

gained, among users of fine steels, somewhat of an unsavory reputation.

In common with many other metallurgists the author believes that electric steel has a practically unlimited future. After it has recovered from its affliction of "swelled head"—and this recovery seems to be practically complete today—we may expect a continued, perhaps sensational development of the electric furnace as a producing medium for fine steels. This development, we hope, will be steady and healthy. True, the electric furnace has its faults, but it also has its virtues. Its virtues are capable of being expanded indefinitely; its faults may be relegated to complete oblivion.

The Present Status of Electric Steel.—Electric steel is, as we have noted, considered by many metallurgists as occupying a field midway between the product of the acid and basic open hearth and the crucible process. This is perhaps the case with much of the present-day product. A portion of the electric steel now being produced is equal in every respect to the finest crucible steel; a large amount stands midway between crucible and open-hearth steel in quality; and a small amount—this is steadily decreasing—is no better and in some cases inferior to good open-hearth steel. This is a condition which should not persist; the electric furnace is capable of making steel, whether a heat of 1 or 50 tons, equal to crucible steel in physical characteristics, even superior to crucible steel in chemical composition. The best electric steel is made today in small units. As a rule the larger hot metal furnaces produce a material that in many cases is little, if any better than open-hearth metal. This is perhaps worth viewing in more detail for a moment.

Hot metal electric furnaces are nearly always operated in conjunction with a large open-hearth plant, in some cases as the final operation of a three-furnace process (Bessemer open-hearth-electric, commonly known as the triplex process). The temptation to hurry, with this mode of procedure, is great. As a result, the partly refined open-hearth metal is given a washing, we cannot call it refining, in the electric furnace. In order to avoid delays at the open hearth and Bessemer, this electrical washing consists of holding the metal under a deoxidizing slag for 30 to 60 min., seldom more than $1\frac{1}{2}$ hr.; hardly sufficient to produce, especially with alloy steels, a completely deoxidized product. The resulting steel is only slightly better, in some cases no better,

than a well made basic open-hearth steel and certainly but little better than good acid open-hearth steel.

In cold scrap melting it is different. No other operations are held up by delays at the electric furnace; the incentive to hurry is not nearly as great, therefore more time can be given to deoxidation and a better steel results. In our later complete discussion of the cold metal process, we will go into this more fully. In addition to the time factor in operating electric furnaces in conjunction with the big open-hearth plant, the employee enters importantly into the quality of the steel.

Electric Furnace Employees.—It is not advisable to discuss in detail the classes of employees necessary to the manufacture of electric steel. We will, however, dwell for a moment here on the importance of good furnace labor as connected with the present-day status of this product.

The advance of the electric process has been so rapid that the supply of efficient furnace melters has lagged far behind the demand. The result has been the operation of many electric furnaces and the production of much steel by men unfamiliar with the process and its possibilities. Most electric furnace melters were recruited from the open hearth. Of course this was the logical thing to do. It has, however, had one bad effect, deoxidation has suffered and consequently the steel has not been of the best quality. In the first place, the final electric furnace slag is so different from the open-hearth slag that scarcely a single characteristic is common to both. For a man working for years with an oxidizing slag the carbide slag presents many difficulties.

In some respects the desulphurizing ability of the electric furnace final slag has been detrimental to final quality when worked by an open-hearth melter. He has paid too much attention to desulphurization and not enough to deoxidation not knowing that *desulphurization does not necessarily guarantee deoxidation* but that *deoxidation does guarantee desulphurization*. This is only natural. After 10 or 15 years "sweating and swearing" in an effort to keep sulphur under control in an open-hearth furnace, it is to be expected that when he works a slag that removes this troublesome element quickly and completely, he will pay too much attention to this feature at the expense of final quality.

The quality of electric furnace labor is improving steadily. A large number of the younger men, who have chosen this branch

of melting and started as helpers on furnaces, have become competent to take charge of one or more units. A majority of these have never worked on any other melting furnace, consequently have no bad habits in furnace practice to overcome and are able to produce steel with a final object of quality in mind.

Summary.—After the foregoing view of the present-day status of the electric process, it is perhaps advisable to summarize briefly.

We have seen that the majority of electric steel melting in this country is accomplished in furnaces of one class, the direct arc of which two modifications or types are in favor; one with a non-conducting hearth, the other with a conducting hearth. We will take up in a later chapter the details of the direct arc furnace and will attempt to show why this furnace is the most successful in steel production and why it has supplanted all other types.

In the present section we have discussed the advantages of the electric process and find that they consist of:

(1) Greater flexibility, permitting any grade or kind of steel to be made.

(2) High quality, producing a steel superior to Bessemer or open hearth in physical properties and chemical composition, and equal to crucible steel in both of these essentials.

(3) Certainty of composition and ease of control permitting the alloys to be added directly to the furnace with no loss; permitting the temperature to be controlled exactly, thus facilitating refining reactions and preventing local overheating; and producing a metal comparatively free from oxidation defects, gases and segregation.

We have also seen that the electric process has some disadvantages as well:

(1) It is too costly to compete where tonnage and cost are the chief requirements in the final product.¹ The prospect of lower cost with increasing development of power resources is probable.

(2) It is, at present, often operated by men unversed in deoxidation and thus a steel is produced that is on an average not quite up to the standard set by the crucible process. A better product will result from a more thorough training for furnace operators in the electrometallurgy of steel.

¹ The electric furnace can compete in the foundry. It will produce high quality steel castings as cheaply as the small converter or open-hearth furnace.

(3) Electric furnaces are frequently installed as adjuncts to the open hearth by companies interested primarily in the production of large tonnages. The electric furnace occupies a field of its own and may with greatest economy and with best results be operated in *conjunction* with another melting operation but should never be operated as an *adjunct* to the process. Washing hot metal in an electric furnace and calling it electric steel has done much to give it a bad name.

Having viewed with some detail the development of the electric process and the present status of electric steel it is quite fitting and essential that we discuss for a few moments its future possibilities.

THE FUTURE OF ELECTRIC STEEL

We wish to repeat again the important point; that electric steel is still in its infancy, that its possibilities are as yet unexplored and that its future is unlimited. We could hardly expect that a process not much more than 20 years old would revolutionize the steel industry in that time. The electric furnace has proved this much, that 50 tons of steel can be produced that is just as good physically, is even better chemically than the best crucible steel made in a lot of 100 lb. Governmental tests have shown that electric furnace high speed tool steel, most of it made in heats of 3 to 6 tons does just as good work, often better work in the actual cutting test, than the best brands of crucible. The government has also proved—we will take this up again—that ordnance steel made in two 30-ton Heroult furnaces each overcharged as much as 75 per cent is from 30 to 100 per cent better than the best acid open-hearth material. We admit that these results are not obtained consistently. This is not the question. We do wish to show in the pages that follow that the electric furnace intelligently operated could do it consistently if desired.

Quality versus Quantity in Steel Production.—The remarkable development of modern steel making and the enormous demand for steel products in the past 50 years has put production and tonnage foremost in the minds of practically every steel maker. Witness the plants of the Pittsburg, Chicago and Birmingham districts where an investment of many millions in blast furnaces, Bessemer converters, open-hearth furnaces and rolling mills has made it possible to produce a finished piece of steel direct

from the ore and coal in the ground, the metal never getting below a red heat in all of the processing. In these plants, steel is produced at the rate of thousands of tons each day. It is certain that quality cannot stand very high under these conditions. Although steel manufacturers in their race for tonnage and their striving to break production records have to a large extent lost sight of quality, they are not the only ones at fault. Engineers in specifying steel products have become accustomed to think in terms of a factor of safety ranging from 50 to 500 per cent. The requirement of such a large factor of safety has done much to discourage quality production.

For many years the only high quality steel produced was made by the crucible process or by a few acid open-hearth plants making a study of a quality product. Making the crucible process a synonym for quality has gradually instilled into the minds of the manufacturer the idea that quality and quantity could not be coexistent; they always thought of quality "as coming in small packages." Considerably less than 10 years ago, the author watched a large manufacturer of Bessemer and open-hearth steel, who probably produced more than 1,000 tons of ingots a day, pick up gingerly and examine carefully, a 10-lb. bar of crucible tool steel for which he had paid 20 cents a pound.

The Difficulty of Obtaining Quality in Ordnance Steels.—As the result of the thought acquired through years of tonnage production, that a quality product could not be produced in quantity, the large manufacturers were woefully inefficient and unprepared when the late war brought an unprecedented demand for high grade steel for Army and Navy Ordnance. The attempts of these manufacturers to produce a high grade product were so futile and the resulting steel so unsatisfactory that the U. S. Government in 1918 appointed a committee of the foremost metallurgists of the country to investigate melting practice. The result was a paper recently published.¹ The sum and substance of this paper boiled down to a few words is: To make good steel it must be deoxidized. The practice as outlined in that paper is the same that has been used for a number of years by one or two plants who have considered quality as the chief requisite in steel manufacture and who, to produce this quality,

¹ W. P. BARBA and H. M. HOWE, Acid Open Hearth Process for Manufacture of Gun Steels and Fine Steels, *Trans., Am. Inst. Mining Met. Eng.*, Feb., 1922.

have retained the acid open-hearth process even at a sacrifice of production records.

If there had been more metallurgists who had studied deoxidation instead of tonnage and speed this governmental investigation would have been unnecessary. To overcome the lack of quality production of ordnance steels in case of an emergency the Government constructed an armor plate and gun plant at Charleston, West Virginia, where electric furnaces are used exclusively in ordnance steel manufacture. Experimentation at this plant for more than a year proved conclusively that the electric process will produce ordnance material in lots up to 100 tons much superior to acid open-hearth steel and very much superior to basic open-hearth steel of like composition.

The Principal Essential of Quality in Steel.—The principal essential of quality in steel is soundness. Soundness cannot be present when the metal contains dissolved or entrapped foreign material, oxides or gases. The recent results of the German investigation on gas, quoted in Chap. VII where it was found that ordinary steels contained 13 to 130 cc. of gas per 100 gm. of metal, equal to 132,000 to 1,320,000 cc. per ton, show quite clearly that a metal cannot be sound unless thoroughly degasified.

It is evident that only the most ordinary grades of steel can be produced by processes that, because they are essentially oxidizing, introduce oxides and gas into the metal right up to the moment of tap and that unless means are taken to eliminate thoroughly all of these oxides and gases, and this takes time, the steel cannot be of high quality. The three processes that permit of a natural and thorough deoxidation and degasification are the acid open hearth, the electric process and the crucible process. Even with the advantages of a slag but slightly oxidizing, the acid open hearth is essentially an oxidizing process and as such can never produce as good steel as the electric or crucible process.

For the manufacture of high grade steel in quantity the crucible must be quickly eliminated; it is practically impossible¹ to produce a large quantity of steel at one time melting in 100-lb. lots. The sole survivor of the melting processes, the one adapted

¹ For many years Krupp in Germany has manufactured guns and armor plate steel by pouring the melted contents of hundreds of crucibles into one ladle. This is not done in America.

to the manufacture of the highest grade of steel in lots of 1 to 100 tons is the electric process.

The Adaptability of Electric Steel to Structural Use.—With a slightly lower power cost steel refined in an electric furnace could economically replace Bessemer and open-hearth steel for structural purposes. It is notorious that most failures in Bessemer and open-hearth steel occur unexpectedly and are often unexplainable. This is the reason for the high factor of safety required by engineers. If in buildings, steel of one-third lighter section could be used, steel produced at a cost not exceeding \$5 a ton more than a similar metal from the open hearth, a saving is at once apparent. It is probable that in the future electric steel will be specified for bridges and other structural purposes especially where resistance to unusual shock, stress and strain is required. It is also probable that the use of electric steel with a lower factor of safety and lighter sections will result from devising a suitable test, whereby an accurate idea of the resistance of the metal to shock or to continued stresses below the elastic limit can be obtained, instead of using as a criterion the present tensile test which is often well nigh worthless as a measure of quality.

The Adaptability of Electric Steel to Rails.—Rails have probably been subjected to more study and more improvement than any other steel product. Railway rolling stock has been increasing rapidly in size and weight; even though rails have increased greatly in size, they have not kept pace with railroad equipment; consequently, the present striving is mainly toward a betterment of their quality so the size may be kept down as much as possible.

Rail failures occur in two ways, breakages—happily these are not frequent—and abrasion. Breakages are usually sudden and are almost always caused by rupture set up through repeated stresses at a point of weakness; a slag inclusion or a blow hole, occasionally the break occurs at a spot that is apparently sound. In any case, the break is undoubtedly caused by a flaw, which even though it is not visible is due to insufficient deoxidation or degasification of the steel in making. Abrasion is always serious especially on curves, and compels frequent rail changes to keep the track in good condition.

Better rails than those now made by the basic open hearth could be made by the electric furnace. By its thorough deoxidation and degasification, breakage could be practically eliminated

and as resistance to abrasion is a well-recognized characteristic of electric steel, rails from the electric process would without doubt greatly out-wear the ones now in general use.

It would be possible to produce rails by the electric process nearly free from sulphur and phosphorus; also, it would be possible to decrease the carbon, securing more ductility without sacrificing hardness. Likewise the manganese could be radically reduced in the electric furnace product. Because it is more free from segregation than open-hearth steel, the rail production from an ingot of given size should be greater in the case of electric steel. There is no doubt but that electric rails are far superior to the open-hearth product at low temperatures. This advantage is especially desirable as most rail failures occur in winter.

Summing up, we may say that assuming that rails can be made by the big electric furnace at a cost not exceeding \$5 a ton more than the corresponding open-hearth product, it is probable that electric steel rails will come into more general use because: (1) They are harder for the same ductility and for the same hardness they are more ductile; (2) they are far superior to open-hearth steel at low temperatures; (3) they are nearly free from sulphur and phosphorus and more nearly free from segregation than open-hearth steel; and (4) they are more resistant to shock and abrasion. In other words, electric steel may be completely freed from oxides and gases, and thus made more sound and uniform.

The Adaptability of Electric Steel to Tools.—The electric furnace is noted now for its production of fine tool steels of both carbon and high speed grades. In this field it has encroached seriously upon the crucible process and will no doubt almost completely replace the latter in the future. Crucible steel has the great advantage of a reputation gained over a period of more than 100 years. It is natural that any innovation would be looked upon with suspicion for a while, when entering into competition with a process as old as this.

We will take up in a later chapter a process for producing tool steel of the highest quality, equal in every respect to crucible steel; a process by which 6 tons of washed metal and muck bar or ingot iron are melted and tapped to produce tool steel ingots. By this means, the crucible process is duplicated exactly in every respect except that 6 tons are produced at a time instead of 100

lb. The question of adaptability of the electric furnace to making carbon and high speed tool steel is so important that it will be dwelt on later in more detail.

It might be said here that the cutting tests required by the U. S. Government on high speed steel show equally good results for steel produced by both the electric furnace and the crucible pot. In no case, over a period of time, has the steel from either process proved superior.

The Adaptability of the Electric Process to Alloy Steels.—In alloy steels, the electric furnace enters its big field; the one in which it can, as time goes on, show if it will, marked superiority. Today, the better class of motor cars specify electric alloy steel almost exclusively, even many of the cheaper ones are using it for parts where resistance to shock and wear are of utmost importance. It is unnecessary to repeat the advantages of the electric process in alloy steel manufacture. The only thing keeping down the advance of electric alloy steel is the cost. When power costs become lower, the electric furnace undoubtedly will assume the greater part of the alloy steel production.

The Adaptability of Electric Steel to Ordnance Manufacture.—The experiments of the U. S. Government at the U. S. Naval Ordnance plant at Charleston, W. Va., in the manufacture of electric steel for armor plate, gun parts and armor piercing shells, have been epochal in the advance of the electric furnace. In the chapter on the hot metal process, the author will take this up in detail and will present the furnace log of a heat of electric armor plate in which nearly 100 tons of molten open-hearth metal were refined in two 30-ton Heroult furnaces and cast into one ingot. Although these plates were still incomplected when operation at that plant was discontinued, the successful refining of this amount of metal in an electric furnace marks perhaps the greatest single advance ever made by electric steel.

Concerning the adaptability of electric steels to ordnance, we could do no better than quote from H. F. Leary's¹ paper before the American Society for Steel Treating. He says:

No definite process is specified for the steel, but it is specified that the forgings shall be made of domestic steel manufactured from the best quality of raw material by an approved process. Successful forgings generally have been manufactured of acid open-hearth steel, and it is

¹ Heat Treatment of Steel for Ordnance Purposes, *Trans.* Jan., 1922, p. 290.

believed that *outside of the electric furnace*, the best results are obtained by this process. The reason for this appears to be that the acid process gives the most homogeneous steel with greater freedom from oxides, segregation of the metalloids and other impurities.

Cases have been found where manufacturers endeavored to use ingots made by the basic process. Although the mechanical and heat treatment was such as would have insured success on an acid ingot, failure on physical test has resulted in one or more of the test specimens taken, and ultimately caused the manufacture to be made of acid steel. . . .

. . . These inclusions generally are believed to be manganese sulphide and silicate and where segregated have always been regarded with suspicion. Later development tends to the belief that the most dangerous element in the steel is the oxide, which appears only as specks under high magnification, but which settles in the ferrite boundaries and weakens the adhesion. *It is to the electric furnace that we must look for improvement in this respect.* (Italics are the author's.)

Commander Leary admits that basic open-hearth steel is unsatisfactory for ordnance, and *that outside of the electric furnace* the best results are obtained from the acid open hearth. In other words, for use in ordnance, steel must be deoxidized more thoroughly than is possible in the basic open hearth. We will attempt to show later by citing the hot metal practice at the U. S. Naval Ordnance plant that electric steel is even more thoroughly deoxidized than acid open-hearth steel.

It is not out of place to predict the almost exclusive use of electric steel for ordnance, steel made in 50-, perhaps even in 100-ton electric furnaces, using for each ingot of armor or gun steel the combined molten contents of two to four furnaces.

The Future of the Electric Furnace in the Foundry.—Although we will, in this book, confine our exposition of electric steel almost exclusively to the manufacture of the ingots, it might not be out of place to discuss the future of the electric furnace in the foundry. The electric process stands supreme in the manufacture of castings because of: (1) The superior quality of the product, (2) the high temperature obtainable by the furnace and (3) the adaptability of the process to both iron and steel.

Because of its freedom from both sulphur and phosphorus, non-metallic impurities and gas, it follows that steel for castings made in the electric furnace will be of exceptional quality. Also, the high temperature attainable in the furnace makes it possible to pour thin and intricate sections with little loss of metal. Because electric steel is uniform and can be made as hot as

desired, there is much less scrap loss than in any other process. Gates and risers may be reduced to a minimum and the loss from defective castings is probably insignificant.

One outstanding advantage of the electric furnace in the foundry is that both iron and steel can be melted and refined in the same furnace. This allows a maximum production of great variety with a minimum investment. Again, the production of better grade iron castings results from the refining of molten cupola iron in an electric furnace.

The electric furnace in small units, mostly 6 tons or under, has practically an unlimited future in the manufacture of castings. Here the cost of power is more than offset by the flexibility and adaptability of the process to a large variety of products and by the small investment required.

The Future of Electric Steel.—We may now summarize briefly the future prospects of the electric process:

(1) With cheaper power, the electric furnace can produce better structural material than is now used, sufficiently superior in quality so that lighter sections can be used, and at a cost but little higher than the present open-hearth-product.

(2) The electric furnace can be used economically to produce rail steel of much better quality than that now being made. The electric steel rail should be especially adapted to those parts of the country where severe climatic conditions prevail and where the additional cost of \$5 to \$10 a ton would be more than offset by using a rail free from non-metallic inclusions, segregation and other flaws.

(3) The electric furnace can replace the crucible process in the manufacture of tools and other high grade steels. This is a condition of the present; the future will probably see further expansion of the electric furnace along this line.

(4) The electric furnace now produces alloy steels of superior quality. If costs can be lowered slightly, it should encroach seriously upon the open hearth in this field.

(5) The expansion of the electric process in the manufacture of ordnance, in view of the experiments already made by the Government, seems to be certain. This expansion hinges, especially for successful armor plate manufacture, on the construction of larger furnaces, even up to 100 tons in size.

(6) The electric furnace has today an assured position in the manufacture of castings, both iron and steel. Due to its flexi-

bility and adaptability to all kinds of work, it will undoubtedly become, in the future, the recognized medium for the production of high grade iron and steel castings.

In view of the above, we can safely predict that in the future electric steel will be specified: (1) For all purposes where it is desirable to use a metal free from sulphur and phosphorus, free from excessive segregation and free from non-metallic impurities and gases; (2) for all purposes where quality is paramount and where wearing ability and resistance to shock are necessary; and (3) for any use where a cost of not more than one-half cent a pound above the cost of the same material from the open hearth is not objectionable.

With the development of hydro-electric power, let us hope that the next 10 or 20 years will advance the electric process to the front rank as a producer of quality steel on a tonnage basis and that by means of the 50-ton, 75-ton or even the 100-ton furnace, electric steel may be produced just as rapidly, almost as cheaply, and 50 to 100 per cent better than the present product of the basic open hearth.

CHAPTER II

MATERIALS USED IN THE ELECTRIC PROCESS

Refractories—Fluxes and Recarburizers—Ferro-alloys—Scrap

The materials used in the manufacture of electric steel are: (1) The refractories for lining the furnace, (2) the fluxes for making the slag, (3) the scrap and (4) the ferro-alloys and other metallic additions made to the metal during refining. It will be better if we confine our description in this present chapter to the four classes of materials noted above and postpone the discussion of electrodes and power until later. Their description will be made more clear if they are considered as an integral part of the electric furnace and as such discussed in that chapter.

The quality of the materials used in electric steel manufacture is a very important item, and affects not only the cost, but the quality of the finished product. Two of the classes are especially important. The high temperature obtainable in the arc furnace has imposed unusually severe conditions on the refractories and has given rise to much study and experimenting on the part of both the user and the maker. Likewise, before the advent of the electric furnace, "scrap was scrap"; in the majority of cases this colloquialism was used in its broadest sense. The electric furnace has, very generally, demanded a selected scrap, selected not only as to its chemical composition, but as to its physical characteristics as well. Again, we may say that the electric process has demanded specialized products from the ferro-alloy industry. Electric steel has demanded new ferro-alloys, alloys unheard of 20 years ago. Also, it has compelled the ferro-alloy manufacturer to meet more rigid specifications than before. In fluxes, the materials used by the open hearth are usually of satisfactory quality for electric furnace slags. Occasionally, the electric furnace plant will purchase their slag-making materials to more rigid specifications than the open-hearth plant. This is more apt to be the exception than the rule. Because of the special quality of materials used by the electric process, we will now take them up in some detail.

REFRACTORIES

The refractories used in the electric process are of two general classes, brick and granular. They may be either acid or basic. The former are used for the lining above the slag line, for the roof in basic furnaces, and for the whole lining in acid furnaces. Basic refractories are used for the bottom and side walls up to a point well above the slag line in basic furnaces. Recently, considerable use has been made of chrome brick for one or two, sometimes more, neutral courses between the acid and basic part of the lining. For parts of the furnace where there is no need of resistance to hot metal or slag, fireclay brick (known as firebrick) may be used. These are also commonly used for ladle linings. Among the other refractories used occasionally are silo-cel, asbestos or fireclay used in a few cases between the brick and furnace shell, and carborundum, used rarely for roofs. As refractories for electric furnaces must withstand very severe conditions, the requirements necessary will be noted briefly.

Requirements for Electric Furnace Refractories.—For use in electric arc steel-making furnaces, refractories should meet wholly or in part at least all of the following requirements:

(1) The softening point and melting point should be high. Although it is desirable to keep the melting point considerably above 3,100 deg. F. (1,700 deg. C.), the melting point is not so important as the softening point. Two bricks may have the same melting point but differ greatly in the temperatures at which they soften.

(2) High density and mechanical strength at high temperatures are necessary. The resistance to load decreases rapidly at high temperatures. Thus a brick must be able to withstand the load imposed at temperatures as high as 3,100 deg. F. (1,700 deg. C.). High density is important as the more resistant a brick to slag penetration the greater the length of its life, with a corresponding decreasing cost. When a brick has become impregnated with slag, its resistance to crushing at high temperatures is reduced more than half.

(3) The refractory should have a minimum coefficient of expansion. The electric furnace is seldom operated over Sunday. With a shut-down of 12 to 24 hr. the furnace may become very cold; on account of its relatively small size it cools much more than the open hearth. In addition, it is heated up much more

rapidly. The first heat on Sunday night is melted in about 3 hr. This means that the temperature increases 700 to 1,000 deg. F. each hour. The need of resistance of the lining to these changes is apparent. In addition to temperature changes over the week end, the charging of cold scrap into a white hot furnace also promotes sudden extreme temperature changes of the lining and bottom, and may cause severe cracking and spalling of the refractories.

(4) The refractory should be resistant to corrosion. In addition to varying temperature conditions, the lining is subjected to varying slag conditions. Both oxidizing and deoxidizing slags are present, one right after the other. Each has its characteristic corrosive effect. Beside actual slag corrosion, the upper walls and lining are subjected to highly corrosive fumes, the worst of which is fluorine from the dissociation of fluorspar.

(5) The refractory should be resistant to abrasion and spalling. Charging cold scrap necessarily imposes severe conditions on the bottom and lower walls. Unless the brick and bottom refractories will stand considerable abrasion, the life of the lining may be materially lessened when some grades of scrap are used. In resistance to spalling, chrome of the common bricks ranks highest, silica next, and magnesite last.

(6) The refractory should have a minimum heat loss through radiation and conduction. We have reserved this requirement for the last as it is open to argument. Formerly, in lining furnaces, firebrick because of their insulating quality were used next to the furnace shell. It was even thought advisable to pack silocel, asbestos or other insulator into a half-inch or inch space left between the shell and the first course of brick. More recently, conduction has been almost favored; linings have been reduced in thickness to aid in conducting away the heat, so that localized overheating of the lining will be prevented. It is claimed that the saving in the additional life of the lining more than compensates for the heat loss.

Refractories Used in Basic Electric Steel Making.—The refractories used in basic electric steel making are silica, magnesite and chrome brick, granular magnesite, dolomite or a prepared dolomitic refractory for the furnace and fireclay and firebrick for the ladles. Magnesite brick and magnesite or a dolomitic refractory are used below the slag line, silica brick above and for the roof, and chrome brick to separate the two.

As a rule the present-day refractories are not wholly satisfactory for electric furnace use. This is principally because the refractory manufacturers have in some cases failed to differentiate between refractories for the electric furnace and those for the open hearth. It has been found in practice that often the brick used for the open-hearth furnace do not give good results in the electric furnace, particularly at or near the slag line. Some refractory manufacturers have asked a premium for brick suitable for electric furnace work; furnacemen who pay this premium very often fail to get what they pay for, and receive material varying in physical properties and suitability even when from the same maker. This situation has not been conducive to much improvement in the quality of electric furnace refractories.

In general, machine-made brick are superior to the hand-made variety, especially in mechanical strength, in resistance to spalling and slag penetration and in accuracy of shape. Slight defects in the manufacture often shorten greatly the life of the brick. For this reason, careful visual inspection is very desirable on all shipments received by the electric furnace plant.

Testing Refractories.—It is probable that too much importance has been attached to physical tests made on brick. Tests sometimes fail to tell anything. Too often in practice two bricks testing the same will vary widely in service. For instance, slag penetration may be much greater when the brick is actually in the furnace than when tested experimentally.

The tests most frequently made, and the ones which probably tell more than any other, are the slag penetration test and hot crushing test. A standard slag penetration test has been adopted by the American Society for Testing Materials.¹ This test in brief is: A refractory ring is cemented on the brick and the whole heated to 2,450 deg. F. (1,350 deg. C.) and 35 gm. of a synthetic slag ground to 40-mesh, whose melting point is 2,320 deg. F. (1,270 deg. C.), is placed in the ring. The whole is then held at the required temperature for 2 hr. The brick is cooled, cut open and the slag penetration measured.

The hot crushing test is a modified form of Brinell. The brick is heated to 2,460 deg. F. (1,350 deg. C.), removed from the furnace and a pressure of 850 lb. is immediately applied on a steel ball 2½ in. in diameter. The pressure is increased to 1,600 lb.

¹ Vol. 20, I, 620-3, 1920.

at the end of 5 min. The depth of the depression is taken as a measure of the resistance of the brick to compression.

In addition to the two tests just described, fusion temperatures are nearly always determined. A portion of the brick, ground fine, is molded into a small cone or pyramid and heated uniformly in a furnace until it fuses. The temperature is usually determined by a pyrometer, sometimes by Segar cones. Other tests occasionally made include expansion, abrasion and impact.

The objection to the laboratory testing of refractories is the difficulty of duplication of actual conditions in practice. This is well-nigh impossible. Laboratory tests are most useful in detecting variations in different shipments and bringing to light bad quality in the same shipment.

ACID REFRACTORIES

The acid refractories are silica brick, used for the upper lining and roof in basic furnaces and for the whole lining in acid furnaces, silica sand used for bottom making in acid furnaces and fireclay and firebrick, the latter used for ladle linings, the former used for repairs, patching and miscellaneous work around the furnace. It will only be necessary to dwell here on the acid refractories as applied to use in basic furnaces as the acid process will be briefly discussed in a later chapter. The latter is confined to the manufacture of castings, being used but seldom in ingot production.

Silica Brick.—Silica brick are made from pure gannister (see Table II) that is, pure silica, SiO_2 , with a little lime added as a binder in the better class brick and a small amount of fireclay in the second class material. For electric furnace use, the silica should be in excess of 95 per cent, preferably about 97 per cent. Silica brick being acid in character¹ cannot, of course, be used where there is any contact between them and a slag containing an excess of bases. They are, therefore, used well above the slag line and for the roof. For this purpose they are better suited than any other material. In the first place they are cheap, not so cheap as firebrick but much more reasonable than either chrome or magnesite. Secondly, they will stand more load when hot than any other of the common refractories having at 2,730 deg. F. (1,500 deg. C.) higher compressive strength than

¹ SiO_2 is the acid anhydride of the various silicic acids.

either magnesite or chrome. Thirdly, silica has a high fusion temperature, about 3,180 deg. F. (1,750 deg. C.).

The principal disadvantage of silica brick, aside from their acid character, is the considerable expansion and contraction they undergo in heating and cooling. When the brick are manufactured they undergo permanent expansion if the burning has been thorough. After placing in the furnace they will expand again with more or less regularity from a low temperature until about 900 deg. F. (480 deg. C.). They then expand rapidly from 900 to 1,200 deg. F. (480 to 650 deg. C.). Above 1,200 deg. F. there is little expansion. The danger with silica brick is through cracking caused by frequent temperature changes through the range 900 to 1,200 deg. F.

Slag penetration weakens silica brick at least 50 per cent. This is not important in the basic electric furnace where the brick do not come into direct contact with the slag but it must be taken into account in acid furnace practice where they make up the whole lining. Silica brick are apt to vary radically in properties in different lots. A typical instance may be cited: A brick made from Ohio silica showed a crushing strength of 100 lb. per square inch at 2,750 deg. F.; a brick from Pennsylvania silica had a strength of only 29 lb. per square inch, also at 2,750 deg. F.

We may summarize briefly.

The advantages of silica brick are:

- (1) They are cheap.
- (2) They have greater strength than other brick at high temperatures.
- (3) They are very refractory.

Their disadvantages are:

- (1) They have a large expansion and contraction at medium temperatures.
- (2) They are likely to be non-uniform.

Taking everything into consideration, silica brick are the most satisfactory refractory for the upper lining and roof in the basic electric furnace.

Fireclay and Firebrick.—Fireclay is a highly refractory material containing silica and alumina in the approximate ratio of 50 to 35. Fireclay is not used to any extent in the lining of the electric furnace; it finds its chief use as a mortar for laying silica brick and for what little patching may be necessary while the furnace is in operation. For the latter purpose it is used in the

spout and to lute the doors. It is also commonly used as a mortar in laying ladle brick and in some shops as a wash or thin coating on the inside of the ladle.

The chemical composition of fireclay is, within certain limits, no indication of its physical properties and ability to withstand high temperatures.

TABLE II.—ANALYSIS OF REFRACTORY MATERIALS¹

Refractory	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Cr ₂ O ₃	Ignition loss
<i>Acid Refractories</i>							
Silica sand	94.37*	2.84	1.86	trace	0.29		0.57
Gannister	98.37*	0.33	0.82	nil	nil		0.49
Silica brick, best	96.29*	0.41	0.51	2.75	0.52		nil
Silica brick, second class	95.37*	1.05	1.57	0.87	1.02		nil
Fireclay	50.07	2.09	38.67*	trace	trace		9.06
Firebrick	52.86	2.58	44.39*	trace	trace		nil
<i>Basic Refractories</i>							
Magnesite, burned	3.07	6.73	1.07	3.06	85.05		0.86
Magnesite, brick	2.45	7.06	0.85	2.87	86.68		nil
Dolomite, raw	1.03	0.43	0.37	27.67	23.25		46.93
Dolomite, dead burned	3.19	1.07	0.87	56.17	38.43		trace
Magdolite	4.05	4.23	0.67	51.35	39.77		nil
Syndolag	4.81	5.37	1.06	49.87	38.51		nil
<i>Neutral Refractories</i>							
Chrome ore	4.87	18.76†	12.73	1.57	14.29	43.16	4.17
Chrome brick	6.89	20.37	9.53	1.83	16.28	44.75	nil

* Contains a small amount of TiO₂, less than 0.5 per cent.

† FeO.

¹ Analyses from the author's private notes.

Fireclay of a quality that fuses at about 3,100 deg. F. (1,700 deg. C.) or higher is calcined, molded either by hand or machine and burned to produce firebrick. The brick, contrary to silica, contract in burning. Machine molding is used for standard shapes, hand molding for special shapes. Firebrick are very common in the big steel plant where they are used for lining heating furnaces, soaking pits, parts of the blast furnace, etc. In melting furnaces, they are used only for those parts of the lining not in contact with molten metal or slag. In the electric furnace, they

are used occasionally for the first course of the lining next to the shell. They are used here principally because of their insulating properties in which respect firebrick rank higher than any other furnace refractory. This practice has been largely discontinued. Firebrick are slightly weaker than magnesite and considerably weaker than silica brick at high temperatures.

Firebrick, in the electric furnace plant, are used chiefly in lining ladles for which use they are the cheapest material and perhaps the best. With first quality brick and tapping steel not too hot, ladle linings last about ten heats.

The other acid materials, silica sand, etc., find no application as refractories in basic lined electric furnaces. Table II gives characteristic analyses of some of the acid refractories.

THE BASIC REFRACTORIES

The two basic refractories are magnesite and dolomite. The first, a nearly pure magnesium oxide is the most important and most satisfactory basic refractory in use. The dolomitic refractories, either natural or synthetic, are essentially high magnesian limestones containing from 24 to 40 per cent magnesium carbonate or magnesium oxide and do not approach magnesite in possessing satisfactory qualities for electric furnace use. Due to the high price of magnesite many substitutes have been offered in the past 6 years. Many of these are patented; all, however, are inferior to magnesite.

Table II which tabulates analyses of electric furnace refractories notes the typical composition of magnesite, both granular and brick, also dolomite and two of the dolomitic refractories.

Magnesite and Magnesite Brick.—Magnesite for refractory use is always calcined; nearly always it is double or "dead" burned. The best grade contains about 85 per cent magnesium oxide, 6 to 8 per cent iron oxide, a small amount, usually less than 5 per cent, of calcium and aluminum oxides. Silica is preferably low as it detracts from the refractory properties.

The granular material is molded and burned into bricks which are used in the basic electric furnace just beneath the granular sintered bottom and for the lining below the slag line.

To be satisfactory for furnace use the magnesite must be of the crystalline variety although it is claimed¹ that when amorphous magnesite is raised to 2,825 deg. F. (1,550 deg. C.) in the presence

¹ R. D. PIKE, *Chem. Met. Eng.*, 23, 1148, 1920.

of 5 to 6 per cent Fe_2O_3 , it is transformed into the hard dense variety known to the steel industry as dead burned magnesite. The same authority states that iron oxide added to magnesite under proper conditions is equivalent in its action to the iron occurring naturally in the refractory.

Most of the magnesite used in this country was, in the past, imported from Austria. The Austrian variety was naturally crystalline and contained about the proper amount of iron oxide (Table II). An effort has been made lately to use the Pacific Coast magnesite which because of its high silica (6 per cent) and low iron (2 to 4 per cent) content has proved to be inferior to the imported. It has been possible, however, to improve the domestic variety greatly by mixing with iron oxide, Fe_2O_3 , or with basic slag high in FeO , then grinding and sintering at a high temperature.

Magnesite is very refractory, its softening point being close to 3,600 deg. F. (1,980 deg. C.). It is not as strong as silica at high temperatures.¹ For this reason and because of its price it is never used above the slag line or for the roof in basic furnaces. Magnesite expands regularly in heating over the whole range below 1,850 deg. F. (1,000 deg. C.). As the expansion is regular the danger of cracking is not as great as with the siliceous refractories.

Dolomite.—As we have already noted, dolomite is essentially a limestone with a very high percentage of magnesium carbonate. It corresponds to the chemical compound $\text{Ca.Mg.}(\text{CO}_3)_2$ and is widely distributed in this country. Dolomite is crushed to about $\frac{1}{2}$ -in. mesh and in this size is used universally as a bottom material for basic open-hearth furnaces and extensively in basic electric furnaces. In electric furnace work it is used principally for repairs, either the raw or calcined material being added between heats. If the bottom is in fairly good shape, the raw refractory is used. If not, calcined dolomite or one of the prepared dolomitic refractories gives better results. In building a new bottom in the electric furnace, calcined dolomite or one of prepared refractories usually a double burned material may be used. Although dolomite bottoms are common, most furnacemen prefer to make their new bottoms of magnesite.

¹ Magnesite brick often crumble and fall to pieces under slight load when the furnace is rapidly heated and cooled. Sometimes, under these conditions, they will not support their own weight.

During the war, when the price of magnesite became excessive, the patent refractories were introduced, the principal ones being magdolite and syndolag. Magdolite is a double burned dolomite. It is claimed that through a patented process of burning it becomes a refractory superior to ordinary burned dolomite. Syndolag is burned dolomite, ground and mixed with about 10 per cent ground basic open-hearth slag. The mixture is then burned again. Syndolag as a rule will have a slightly higher iron oxide content than dolomite (see Table II).

General Advantages and Disadvantages of the Basic Refractories.—The basic refractories have no decided advantages over the acid. They are, in fact, inferior to them in almost every respect. Magnesite has a high fusion temperature and an even rate of expansion and contraction. In contrast to this it is relatively weak at high temperatures and in addition—this is the greatest disadvantage—it is very costly. Dolomite and the other refractories of this class, vary greatly in physical properties, have variable fusion points and are prone to slake. The last disadvantage may be in part overcome by calcining at a very high temperature.

As a result of the generally unsatisfactory character and high price of the basic refractories they are used only where absolutely necessary, that is, on the bottom and that part of the lining below the slag line, never above the slag line nor for the roof. There is considerable promise for a general improvement in basic refractories. The manufacture of magdolite and syndolag was a step forward, in that it produced a moderate-priced refractory that was much superior to dolomite. At the present time, the Government is undertaking a large amount of investigation work toward an improvement in dolomitic refractories. This is another step forward, and may result in making the steel makers of this country independent of imported magnesite.

NEUTRAL REFRACTORIES

Chrome Ore and Chrome Brick.—The only commercial refractory of the neutral class is chrome ore, sometimes known as chromite, containing 35 to 45 per cent chromium oxide, Cr_2O_3 , and 15 to 25 per cent iron oxide, FeO . It is highly refractory and in the form of bricks is used, commonly in the last few years, to separate the basic part of the lining from the

acid part above it thus preventing the magnesite bricks from fluxing the silica bricks as might be the case if an acid layer adjoined a basic one. Because chrome brick are neutral in character neither silica nor magnesite brick have any chemical action with them at the temperature attained.

One great advantage of chrome brick is their resistance to spalling. In this they are superior to any other furnace brick. They are not as strong as silica at high temperatures but still are not as weak as magnesite. Chrome brick are usually very uniform in character. Their chief disadvantage is cost, being slightly less expensive than magnesite but much more costly than silica or firebrick. Chrome ore is rarely used as a refractory, the brick being the form usually employed.

Other Neutral Refractories.—With the exception of chrome brick neutral refractories have not come into extended use in electric furnace linings. They are not, as a rule, commercially possible being in their present state of development too costly for daily use. The most common of the other neutral refractories are the synthetic electric furnace refractories¹ of which carborundum is the best known. This material is silicon carbide, SiC , and has been used occasionally as a roof material in instances where silica brick have failed to give satisfactory results. Its cost has prevented more extended use. For the walls, especially below the slag line, it would be unsuitable as it is appreciably dissolved by molten metal with subsequent enrichment of the bath in both carbon and silicon.

A refractory, comparatively new, but which seems to give promise is zirconia, ZrO_2 . Bricks have been made and have been tried experimentally, so far without supplanting the refractories now in common use.

FLUXES AND RECARBURIZERS

The fluxes used for slag making in the basic electric process are limestone and iron ore or scale in the oxidizing period, and lime, coke and fluorspar in the deoxidizing period. In addition, silica sand, powdered glass and crushed ferro-silicon are sometimes used. The function of the flux is to form an easily fusible slag which by its action removes undesirable impurities from the charge, and by covering the molten metal completely serves

¹ That is, manufactured in electric furna

to protect it from gases that may be present in the furnace, and in the final period from undue carbon absorption from the electrodes. As the process is basic, it follows that the slags carried must be strongly basic due to a preponderance of active calcium oxide, CaO . Magnesium oxide always present in the fluxes is not of much value as an active base. In addition it prevents, in part at least, the fluidity that is sometimes desirable as a slag condition.

Limestone.—The limestone used in the melting period of the electric furnace should be nearly pure calcium carbonate with impurities; *i.e.*, silica, combined oxides of iron and aluminum, and magnesium oxide; not exceeding 5 per cent, at most 6 to 7 per cent. The grade commonly used for the blast furnace is satisfactory for the electric process. It is not absolutely necessary to keep the silica (SiO_2) below 1 per cent as is desirable in the basic open hearth. It should, however, be below 5 per cent when iron ore or roll scale is used. In case no ore or other form of oxygen is present except the little on the scrap as rust, a very pure limestone together with the small amount of dolomite bottom that comes up will produce a sticky slag, one needing fluorspar to thin it sufficiently to remove. A stone containing about 5 per cent silica is convenient under these conditions.

The size common for the blast furnace and open hearth, about 8-in. mesh or larger, known around the mill as "man-sized stone," is too large for electric furnace use. The best size is about 4-in. mesh; even smaller, down to 1-in. mesh, can be used satisfactorily.

Iron Oxide for the Oxidizing Slag.—Three forms of iron oxide are commonly used, iron ore, scale and when the scrap is small in size and rusty, the oxide on the scrap. If ore is used, it should be high grade; a clean, hard Bessemer hematite is best. A low phosphorus ore should always be used; it is of course undesirable to introduce any more of this element into the charge than is necessary. The amount of silica, provided it is below 10 per cent is unimportant although if a low silica limestone (2 per cent or below) is used, this constituent may be as much as 15 per cent. The small amount used in a heat makes it unnecessary to be too strict in the composition of the ore.

Many shops use the roll, forge or hammer scale that collects around the plant rather than purchase ore. Scale is just as good as ore, in fact it is somewhat better as it has no undesirable

gangue, being nearly pure iron oxide (Fe_2O_3). Except for being more economical, scale has no further advantage over ore. Also, too much sulphur may be present in scale. This may be a decided disadvantage if sulphur specifications in the steel are low and if the scrap and slag-making materials contain close to the limit of this element. If the scrap and slag are low in sulphur, the amount in the scale may be entirely disregarded.

Lime.—Lime is the most important flux used in the electric furnace and is the foundation for the final or deoxidizing slag. It is calcined limestone and may be purchased in many grades. Table III notes three of these grades received recently by an electric furnace plant. The one noted as good is a little above the average. The fair grade has too much magnesium oxide and loss on ignition. The poor lime is too high in silica, magnesium oxide and loss on ignition.

TABLE III.—ANALYSES OF FLUXES¹

Flux	SiO_2	Fe_2O_3 + Al_2O_3	CaO	MgO	CaCO_3	MgCO_3	Loss on ig- nition	S
Lime-stone, good	0 95	0 91			96 55	1 37		trace
Lime-stone, fair	1 07	2 19			93 62	3 21		.011
Lime-stone, poor	6 25	1 97			84 47	7 32		.017
Lime, good	2 06	1 83	87 47	4 67			3 56	085
Lime, fair	4 55	2 61	77 25	8 42			6 47	158
Lime, poor	10 27	2 86	62 73	16 25			7 55	380
					CaF_2	CaCO_3		
Fluorspar, good	1 78	1 55			93 27	3 04		.052
Fluorspar, fair	2 31	2 06			90 45	4 75		.143
Fluorspar, poor	4 25	1 78			84 20	8 85		.368

¹ Analyses taken from the author's private notes.

The loss on ignition is mostly carbon dioxide from insufficient calcination of the stone, together with some water of hydration. In general, the lime should not exceed 6 per cent carbon dioxide and should not be hydrated to any appreciable extent. On the

other hand a dead burnt lime, nearly free from carbon dioxide seems to dissolve¹ with difficulty in the slag.

The lime should be low in sulphur. We shall see in a later chapter that the final slag of the electric process has a very well-defined saturation point for sulphur. Consequently, the more of this element in the slag-making materials the more difficult the removal of sulphur from the steel. It is desirable that the lime contain less than 0.1 per cent and essential that the sulphur be below 0.2 per cent.

Fluorspar.—Fluorspar is a most valuable aid to the manufacture of good electric steel. It is neither acid nor basic in itself, although it breaks up into lime and thus becomes a base after being acted upon by the arc. The analyses of the samples marked good and fair in Table III are characteristic of the grades received for the electric furnace. Here again, it is important that sulphur be low, preferably under 0.2 per cent. The presence of considerable sulphur in the spar can often be detected visually. It occurs as sulphides of lead, barium and zinc, more often the former and can be noticed as dark granules or particles in the material.

Fluorspar for electric steel making is normally a washed gravel of glassy luster, often transparent and crystalline. It melts at a comparatively low temperature, about 1,700 deg. F. (935 deg. C.) although the melting point is largely dependent on its purity and consequently may vary widely.

Very little poor fluorspar is on the market, most of it contains 85 per cent or more calcium fluoride, less than 5 per cent silica, 10 per cent calcium carbonate and 0.15 per cent sulphur. The percentage of calcium carbonate is not important except as it influences the melting point; silica of course is undesirable in that it is an acid constituent that detracts from the efficiency of the basic slag.

In addition to its valuable property of conferring fluidity upon the slag, it has been proved by a large number of investigators that fluorspar is active in desulphurizing. This action is independent of and in addition to the desulphurization accomplished by having a slag strongly basic and very fluid. The desulphurizing action of the flux which we will discuss again, while not of as much value in the electric furnace as it is in the basic open hearth, is of no small moment and is the principal reason why this

¹ We have used "dissolve" for want of a better word. Actually the lime melts through the formation of various low-melting silicates and as such, diffuses through the body of slag.

material is preferred to silica sand, powdered glass or other fusible substances used in its place.

Other Fluxes.—The other fluxes which have not already been described are coke, used in making the deoxidizing slag, silica sand used in some plants to partly or wholly replace spar, and powdered or crushed glass used occasionally for the same purpose.

The quality of the coke used in the building of the slag is not of special importance; many plants used the cheaper coke breeze instead of the regular size. In any case it is ground to a powder, 10-mesh or finer, before being used in the furnace. The only essential in the coke is freedom from moisture which would naturally waste heat in the furnace.

The grade of silica sand containing 95 per cent or more silica, SiO_2 , used commonly in the acid open hearth is satisfactory for the electric furnace if this material is used at all. Powdered glass is cheap and satisfactory as a substitute for silica sand. It does not need to be powdered, if crushed to pieces not exceeding 1 in. in size.

For quieting the metal after recarburizing many melters use crushed ferrosilicon (50 per cent). This material usually can be purchased very reasonably from manufacturers of 50 per cent ferrosilicon who screen out the fines from their regular product, and who are glad to dispose of it at almost any price.

Recarburizers.—Three materials are used as recarburizers, carbon, washed metal and pig iron. Of the first crushed coke, crushed anthracite coal or crushed electrodes is used. Crushed electrodes is the favored form of carbon as it affords a ready means of using up the butts and broken pieces that always accumulate in the melt shop. The carbon absorption is a little higher with electrodes, (65 to 70 per cent in the bath and 75 to 80 per cent in the ladle) than with either anthracite coal or coke. Good furnace practice tends to keep away from this form of recarburization altogether.

Washed metal is the ideal recarburizing agent. It is pure iron containing 3 to 4 per cent carbon, all combined. Impurities in appreciable amounts are absent. Several grades are available, the two commonly used for electric steel making are the very pure, sulphur and phosphorus each under 0.02 per cent, and the next grade in which these elements are below 0.025 per cent. The material all comes in "man-sized" pieces, either slabs or broken chunks weighing about 50 lb., convenient and easily handled.

Instead of washed metal, pig iron is often used for recarburization. This is an iron made especially for recarburization purposes, and has commonly less than 0.03 per cent sulphur and 0.03 per cent phosphorus, sometimes below 0.025 per cent. The carbon range is about the same as washed metal. Low phosphorus pig iron is used when it is desired to substitute a cheaper material for washed metal.

FERRO-ALLOYS

The ferro-alloys used in electric steel manufacture may be divided into three classes: (1) Ferro-alloys essential to the metal irrespective of the kind of steel made, (2) ferro-alloys used in making the common alloy steels and (3) the rarer ferro-alloys used occasionally either for the preparation of steels with special properties, or for experimental purposes. In addition, one or two alloys, notably metallic aluminum and ferrotitanium, are sometimes used for final deoxidation. These two materials, more or less common in the basic open-hearth plant have not come into extended use in the case of electric steel.

The ferro-alloys necessary for every steel, both plain carbon and alloy are the iron-manganese alloys, ferromanganese and spiegel; and the iron-silicon alloys, ferrosilicon. For the more common alloy steels, ferrochromium, metallic nickel, and ferrovanadium are used; ferrotungsten also if high speed steels are made. The more unusual alloys include metallic copper; molybdenum either the metal, ferro-alloy or calcium salt; ferro-uranium, ferrozirconium and cobalt.

Ferro-manganese and Spiegel.—The iron-manganese alloys are made in two grades, both being the product of the blast furnace. Ferromanganese contains 80 per cent manganese; spiegel, the low manganese variety, 20 per cent. As the manganese ore is necessarily reduced with carbon in the blast furnace both varieties contain considerable of this element, the ferro has commonly 6 to 7.5 per cent, the spiegel will average a little lower, being about 5 per cent. See Table IV.

Considerably more than half of the ferromanganese used in this country is imported from England. There is little difference as far as composition is concerned between the imported and domestic varieties, the English ferro being as a rule a little lower in carbon and slightly higher in phosphorus than the domestic. Ferromanganese contains no sulphur, the high working tempera-

ture of a furnace smelting manganese ore, and the affinity of manganese for sulphur, serving to remove this element completely. Phosphorus is the only harmful element present; the percentage of this is too low to figure importantly unless very low phosphorus steel is made. For an average it may be said that from 1 to 3 points (0.001 to 0.003 per cent) of phosphorus will be introduced into the metal by the manganese addition.

Both spiegel and ferromanganese, as now produced, contain very nearly 20 and 80 per cent manganese respectively. A variation of more than 1 per cent plus or minus is uncommon. The 70 per cent variety produced during the war has been almost totally superseded by the 80 per cent alloy.

For special uses a carbon free ferromanganese and manganese metal are made by aluminum reduction (thermit) methods. This alloy is much more expensive than the common variety and is, consequently, used only when the introduction of any carbon into the metal is prohibited. This is never the case with commercial alloy steels.

Characteristic analyses of ferromanganese and spiegel are given in Table IV.

TABLE IV.—ANALYSES OF THE IRON-MANGANESE AND IRON-SILICON ALLOYS¹

	Iron-manganese alloys			Iron-silicon alloys		
	Ferromanganese		Spiegel	Ferro-silicon, electric furnace	Ferro-silicon, blast furnace	
	U. S.	English				
Carbon	7.17	6.52	5.13	0.67	0.35	2.25
Silicon	0.87	1.37	0.94	48.95	50.37	10.28
Sulphur				0.015	0.027	0.017
Phosphorus	0.228	0.264	0.095	0.137	0.087	0.113
Manganese	80.37	80.17	19.78	0.31	0.22	0.86

¹ Analyses from the author's book, "Technical Analysis of Steel and Steel Works Materials," McGraw-Hill Book Co., New York, 1923.

Ferrosilicon.—Ferrosilicon is made in two grades. One contains 8 to 15 per cent silicon and is nearly always made in the blast furnace; the other contains 50 per cent silicon and is the

product of the electric furnace. The low silicon variety is rarely used in electric furnace work, it is better adapted to the Bessemer and open-hearth processes. The 50 per cent alloy is used universally in electric steel making. It contains beside silicon and iron, up to 2 per cent carbon and small amounts of sulphur, phosphorus and manganese.

In the electric furnace alloy, the percentage of silicon varies from 48 to 51.5. Above this higher figure, the alloy tends to disintegrate and break up spontaneously into a powder. This disintegration is often accompanied by the evolution of a gas which has caused explosions when the alloy was confined tightly in barrels.

The 50 per cent alloy is made from silica sand, steel or iron scrap and coke in an open top electric furnace. The raw materials are fed continuously into the furnace, the molten alloy is tapped out at intervals and run into slabs to cool, after which it is broken up into pieces about 4-in. mesh. The fines resulting from the crushing of these slabs are screened out and are used by some plants to kill wild metal after recarburizing and sometimes in slag making.

Metallic Nickel and Ferrochromium.—Metallic nickel containing 98 to 99 per cent of the element is used for the manufacture of nickel steel. It is added to the furnace in the form of nickel shot or in ingots or pigs weighing about 50 lb. each. Nickel contains no other elements worth considering.

TABLE V.—ANALYSES OF FERROCHROMIUM¹

	6 per cent carbon		8 per cent carbon		2 per cent carbon	Carbon-free
	1	2	1	2	1	1
Chrome	68.73	65.42	69.53	67.31	71.37	70.67
Carbon	5.87	6.35	8.66	7.91	2.07	0.23
Silicon	2.25	6.82	0.87	1.68	0.64	0.37
Sulphur	0.065	0.037	0.081	0.067	0.037	0.017
Phosphorus	0.071	0.086	0.058	0.074	0.043	0.046
Manganese	0.37	0.28	0.56	0.30	0.21	0.04
Aluminum	*	*	*	*	*	0.47

* Not determined.

¹ Analyses from the author's book, "Technical Analysis of Steel and Steel Works Materials," McGraw-Hill Book Co., New York, 1923.

Ferrochrome is made by the reduction of chrome ore, $\text{Cr}_2\text{O}_3 \cdot \text{FeO}$, with coke in an electric furnace. Four grades are produced, all having about the same chromium content, 60 to 75 per cent. The difference in the grades is in the carbon. The cheaper alloy, the one always used if possible, is the high carbon containing 6 to 8 per cent of this element. Where the introduction of so much carbon would be undesirable in the steel, two other grades, the 2 per cent and the carbon free (below 0.5 per cent) both considerably more costly, may be used. To produce the low carbon varieties the high carbon material is melted in an electric arc furnace and the carbon removed by the addition of chrome ore and suitable slags. It is difficult to remove the carbon to a low point, hence the excessive cost of the carbon free variety. Much of the latter is now made by aluminum reduction; the thermit process. Table V gives some characteristic analyses of the iron-chromium alloys.

Ferrovandium and Ferrotungsten.—Ferrovandium is made by three methods; reduction by carbon or silicon in an electric furnace, reduction by aluminum by the thermit process, and as a by-product in radium and uranium manufacture. The vandium content ranges between 25 and 40 per cent, nearly always the latter. It may contain a variable amount of carbon; usually this element is low. The percentages of sulphur, phosphorus and manganese are in most cases inconsequential. Silicon may be high in the alloys made in the electric furnace, as much as 16 per cent has been found. Ferrovandium as a by-product from radium manufacture may contain some uranium (No. 4, Table VI). Characteristic analyses of some of the iron-vandium alloys are given in Table VI.

Tungsten is added to steel in either of two forms, the ferro-alloy, containing 65 to 80 per cent tungsten (Table VII); and as the metal. In the latter form it is usually a powder containing in excess of 90 per cent tungsten. The ferro-alloy is preferred by most furnacemen because, as we shall see in a later chapter, the powder is too difficultly fusible and sometimes gives trouble after being added to the bath.

During the war one or two plants used tungsten ore to replace both the ferro-alloy and the powder, reducing the oxide to the metal in the furnace. This practice is not common and its advantages are doubtful.

TABLE VI.—ANALYSES OF FERROVANADIUM¹

	1	2	3	4
Vanadium	40.27	34.53	39.47	37.04
Iron	*	61.49	*	59.68
Aluminum	*	0.23	0.43	0.66
Silicon	9.43	2.78	3.65	0.59
Chromium	none	none	*	0.61
Manganese	0.43	0.35	0.09	0.16
Sulphur	*	0.046	*	0.097
Phosphorus	*	0.117	*	0.136
Carbon	0.37	0.39	0.47	0.36
Uranium	*	*	*	0.73

* Not determined.

¹ *Loc. cit.*TABLE VII.—ANALYSES OF FERROTUNGSTEN¹

	1	2	3	4
Tungsten	79.35	63.85	71.48	82.47
Carbon	0.75	2.03	0.43	0.37
Silicon	0.26	1.57	0.87	0.53
Sulphur	0.032	0.037	0.017	0.023
Phosphorus	0.027	0.059	0.044	0.038
Manganese	0.17	0.26	0.19	0.08

¹ *Loc.cit.*

In addition to high speed steels which take most of the tungsten used, a small tonnage of tungsten magnet and finishing steels is made containing about 5 per cent of the element. Aside from these two grades, tungsten as an alloying element is not common.

Ferromolybdenum and Copper.—From the investigation of the U. S. Navy and others, it is probable that the use of both ferromolybdenum and copper either alone, together or with other alloys will increase greatly in the next decade. As these steels are somewhat of an innovation we shall speak of them again.

Molybdenum may be added to steel as a ferro-alloy, the metal or as calcium molybdate. In either form it goes directly into the metal and stays there. The ferro-alloy has commonly 70 to 80 per cent molybdenum, the powder (see Table VIII) has generally in excess of 90 per cent.

Calcium molybdate is a very desirable form in which to add molybdenum to steel. It has no detrimental impurities and can be made more cheaply per unit of contained molybdenum than the ferro-alloy. Many furnacemen believe that the CaO present prevents possible volatilization of the molybdic anhydride, MoO_3 . The anhydride is completely and easily reduced in the bath to molybdenum.

Copper, like nickel, is added in the form of the pure metal which is easily obtainable. It is not used to any extent in electric furnace practice, to date the only practical use for steels containing copper is the material made by the Bessemer and open-hearth processes and used for roofing, sheet metal and other products where resistance to rust and corrosion is desirable. The amount of copper in steel for this purpose is 0.2 to 0.3 per cent. A very recent experiment in alloying copper to steel was carried on by the Government at the U. S. Naval Ordnance plant. Results were incomplete when operation was discontinued, but what tests were made indicated that 0.5 to 1 per cent both with and without molybdenum was beneficial, and gave practically the same results in physical properties as nickel.

Ferrouanium and Cobalt.—Both ferrouanium and cobalt have been used in high speed steel. Their addition to this grade of material is of doubtful value. Of the two, cobalt probably produces better results than uranium.

Cobalt is added similarly to nickel and copper, and like these two metals dissolves at once and completely in the molten bath. No oxidation of the element occurs after once it is in solution in the steel.

Uranium is used as the ferro-alloy containing 40 to 60 per cent uranium and considerable carbon. The metal oxidizes with great ease, consequently, it is very difficult to keep in the steel. Best results have been secured by adding the powdered ferro-alloy in small doses to the ladle. Not more than 50 per cent of the contained uranium goes into the metal. Better results would probably be obtained by the use of a high uranium, low carbon ferro-alloy, instead of the present alloys containing about 4 per cent carbon.

TABLE VIII.—ANALYSES OF FERROMOLYBDENUM AND FERROURANIUM

	Ferro- molybdenum ¹		Molyb- denum powder ¹	Ferro- uranium ²	
Carbon	2.47	3.23	0.17	3.47	4.71
Silicon	0.51	0.73	1.25	0.81	0.65
Sulphur	0.037	0.021	0.036	*	*
Phosphorus	0.026	0.039	0.095	*	*
Manganese	0.06	0.12	trace	*	*
Iron	17.31	19.37	0.36	*	*
Molybdenum	79.58	75.43	92.37	*	*
Uranium	*	*	*	43.49	51.60

* Not determined.

¹ *Loc. cit.*

² Analyses from the author's private notes.

Ferrozirconium.—Ferrozirconium has aroused considerable metallurgical interest, although results obtained by its use have been, to date, of practically no importance. The author witnessed several experiments¹ in adding this element to steel and has read of other tests² on all of which results were meaningless. The ferro-alloys now produced (see Table IX) are not at all suitable for making experimental zirconium steels as the percentage of the other elements is so great—in many cases equal or greater than the zirconium—and the addition of the ferro-alloy would introduce such large amounts of these elements, that it is doubtful whether any exceptional results obtained could be attributed to the zirconium, to the other elements or to both. One heat recently made³ using alloy No. 1 Table IX contained 0.23 per cent zirconium and 0.87 per cent silicon. The physical properties were considerably better than a plain carbon heat of the same composition but the question at once arises: Are these superior results caused by the zirconium, by the silicon, or by one element intensifying the effect of the other? Thus it is seen how complicated the results may become.

¹ Experiments in 1919 and 1920 at the plant of the Hess Steel Corp., and in 1921 at the U. S. Naval Ordnance plant.

² GILBERT and MACK, Experimental Production of Alloy Steels, Bureau of Mines, *Bulletin* 199, 1922.

³ U. S. Naval Ordnance plant, 1921.

It is very difficult to retain the zirconium added to the steel. It oxidizes very easily. In addition, the ferro-alloy contains appreciable, sometimes large, amounts of titanium, silicon, aluminum, even calcium, all easily oxidizable. The deoxidizing properties of ferrozirconium are so strong that it is even probable that superior physical tests might be the result of a more complete deoxidation of the steel.

Zirconium as an alloy is thus mentioned here in considerable detail, not because of its present importance, but because it is possible that when purer alloys of iron and zirconium are manufactured, alloying this element with steel may produce superior, perhaps sensational properties.

TABLE IX.—ANALYSES OF FERROZIRCONIUM¹

	1	2	3	4
Zirconium, Zr	35.50	28.60	24.36	33.65
Iron, Fe	16.78	38.17	45.74	10.28
Silicon, Si	43.73	16.25	20.76	9.58
Aluminum, Al	2.59	5.83	5.25	3.07
Titanium, Ti	0.75	4.88	3.75	1.86
Nickel, Ni	none	*	*	40.65
Chromium, Cr	none	none	none	0.35
Calcium, Ca	0.34	3.30	*	*
Magnesium, Mg	none	2.48	*	*
Manganese, Mn	0.09	0.14	*	*
Carbon, C	0.41	0.27	0.33	0.65
Sulphur, S	0.065	0.070	0.083	0.097
Phosphorus, P	0.057	0.040	0.087	0.133

¹ *Loc. cit.*

* Not determined.

Ferrotitanium and Aluminum.—These two materials are often called the final scavengers of steel. They are used, commonly in the basic open hearth, more rarely in the electric furnace, as a final addition to complete the deoxidation. They are nearly always added to the furnace just before tap or into the ladle during tapping. In cases of extreme necessity, never however, in good practice, they are added to the mold while pouring.

Ferrotitanium has proved itself of great value in the final deoxidation and degasification of open-hearth steel. It is probably of much less value in electric steel and consequently

has never become popular. It is added as ferrotitanium (No. 1 and 2, Table X) or as ferro-carbon-titanium (No. 3 and 4, Table X).

Aluminum is a very efficient degasifier and is used to quiet wild metal in the furnace, ladle or ingot mold. Its reaction products, as we shall see later, are harmful producing a condition where the "cure is worse than the disease." When an electric furnace melter uses aluminum, he virtually admits either his ignorance of good furnace practice or that he is too lazy to deoxidize and degasify his steel in the furnace.¹ In shops producing high grade electric steel the use of aluminum is practically prohibited. Aluminum when used, is the pure metal either in sticks weighing 1 to 2 lb. or "in pencils," small sticks about $\frac{1}{2}$ in. in diameter.

TABLE X.—ANALYSES OF FERROTITANIUM¹

	1	2	3	4
Titanium, Ti	9.31	19.37	10 23	7 38
Carbon, C	0.38	0.13	6 73	7 07
Silicon, Si	0.57	2.74	1 11	0.95
Sulphur, S	0.036	0.027	*	*
Phosphorus, P	0.093	0.107	*	*
Manganese, Mn	0 43	0.47	0.37	0.65
Aluminum, Al	1 75	3 18	*	0.41

¹ *Loc. cit.*

* Not determined.

SCRAP

The classes and grades of scrap suitable for electric melting are limited in number. All of it is restricted to what is known as shoveling scrap, that is, scrap of comparatively small size suitable for hand charging. The usual open-hearth scrap, yehav melting, cannot be used except in very small doses in the electric furnace. The electric furnace has one great advantage over the open hearth in scrap supplies; it can melt the small material without appreciable oxidation and so with little loss. This has opened

¹ This holds for the manufacture of high quality ingots. The use of aluminum is common and quite justified in the manufacture of castings where blow holes are not tolerated and where a few minute slag inclusions may be practically harmless.

to the electric furnace a large supply of cheap scrap practically unsuited for any other steel-making process.

Classes of Scrap Used in the Cold Scrap Process.—In the manufacture of all varieties of electric steel, three kinds of scrap are commonly kept on hand: (1) Mixed scrap, (2) selected low phosphorus scrap and (3) alloy scrap. The first class is a widely varying mixture¹ and contains almost anything. It is the scrap gathered by the small junk dealers who have no knowledge of steel nor no facilities for sorting; and contains steel, both heavy and light, high phosphorus and low phosphorus, and considerable scrap cast iron nearly always high in phosphorus. The absence of alloys can almost positively be assured in mixed scrap.² Selected low phosphorus scrap is purchased with a guaranteed analysis; the phosphorus is specified to be below 0.04 per cent. It is somewhat more expensive than mixed scrap, averaging about \$5 a ton more.

Alloy scrap is purchased with a guaranteed alloy content; usually only the nickel is specified, sometimes the chrome as well. It is, of course, never high in either sulphur or phosphorus and is nearly always of the proper size for small electric furnace charging. Much desirable scrap, rails and plate for example, must be cut small enough so it will go in the furnace doors. This adds to the cost of electric furnace low phosphorus material.

It is very essential that the proper specifications be imposed and that a rigid inspection be made on all scrap purchased for the electric furnace. Upon the proper charging of the furnace depends to a large extent the speed in melting. For proper charging the furnaceman must have at his command, scrap of various grades and sizes, ranging from the billet and bloom crop end and the 3-ft. section of a rail, down to the punchings and machine turnings.

Selected Low Phosphorus Scrap.—This is the principal basic used by the small electric furnace. It includes all manner of basic open-hearth scrap such as bloom, billet and bar ends, rail crop ends, boiler plate, turnings, punchings, forge scrap, etc. As

¹ Mixed scrap in some localities, especially in the East, is known as "country mixed." This colloquialism has probably resulted from the source of the scrap; most of it is collected by junk dealers in small towns and shipped to the steel centers where it is handled by the larger scrap dealers.

² This is no longer true. Due to the rapid expansion of the automobile, much mixed scrap is becoming contaminated with material containing alloys.

long as the phosphorus content is maintained well below 0.04 per cent, other elements may be disregarded. This is the ideal scrap for use in average practice. For carbon steel heats it may be diluted with about 25 per cent of the mixed grade.

The principal disadvantage and danger in the low phosphorus scrap, as sold to electric furnace plants, is from contamination by nickel. This element is not permitted to be present in appreciable amounts in high carbon tool steels. It has been only recently, in the past 8 or 10 years, that scrap dealers have tried to sort their scrap and keep the carbon scrap free from alloys. Before that time, alloy scrap was mixed rather promiscuously with the carbon variety. The result is that carbon steel made from an all-scrap base always contains some nickel, from a trace to 0.3 per cent. In addition, as nickel cannot be removed from steel, the amount is continually increasing each year. The only class of steel now entirely free from nickel is that made from a base of pig iron, such as Bessemer or in some cases, open hearth.

Alloy Steel Scrap.—The principal alloy scrap is nickel; chrome nickel is not so important, is cheaper, and is usually less desirable than scrap in which chromium is absent. The chrome is lost by oxidation and causes undesirable slag conditions. Occasionally, the plant can secure sufficient chrome, chrome nickel, or chrome vanadium scrap of a quality high enough for white slag melt-downs.¹ In this case all of the alloying elements are retained by the metal and not lost by oxidation. To take advantage of the lower cost of the white slag melt-down practice, electric furnace plants aim to keep the scrap from their own rolling mills and forges separate from purchased scrap thus saving all of the alloys present by melting their own scrap under a white slag. White slag melt-downs will be discussed in a later chapter.¹

It is always advisable to use as much nickel scrap as possible in making nickel steel. The additional cost of nickel scrap over low phosphorus material is always less than the cost of the metallic nickel represented by the percentage in the scrap. For this reason, nickel steel can be made more cheaply using nickel scrap with a small final addition of metallic nickel than if carbon scrap is used and adding all of the nickel as the metal.

High speed scrap is often used in the manufacture of this steel. This practice is usually much cheaper but demands skilful furnace operation to save a large part of the alloys.

¹ Melting without oxidation, see Chap. VIII.

Alloy scrap is nearly always of a size most desirable for hand charging. It is often the product of the forge plant and the automotive manufacturers. A large part of alloy scrap is gears, camshafts, axles, steering knuckles, billet and bar crops, etc.

It is essential for a good product and a rapid operation of the electric furnace that all scrap be as clean as possible and free from rust and scale. Dirt, excessive rust and scale promote heavy furnace losses and too much oxidation.

CHAPTER III

ELECTRIC ARC FURNACES—GENERAL CONSIDERATIONS

Methods of Heating by Electricity—Classes of Arc Furnaces—Power Supply for the Arc Furnace—Electrodes—Thermal Efficiency of the Direct Arc Furnace

We do not intend, in the next three chapters, to describe in detail the different electric furnaces used in steel making. There are several excellent texts now published that take up the various furnaces with due regard to their mechanical, electrical and thermal efficiency. Rather, in describing the process of steel making, we will enumerate the general features of the arc furnace; describing in some detail the Heroult, the most popular furnace and the one leading in instalations; only looking at the other furnaces briefly, comparing them with the Heroult as far as steel-making ability is concerned. We may say that the general procedure of making electric steel is the same in all furnaces of the direct arc type of which the Heroult is the outstanding example; the slags used for refining are much the same; the chemical reactions are much the same.

In general, all of the direct arc steel-making furnaces whether they have a conducting or a non-conducting hearth will produce a high quality steel; the difference between them lies principally in mechanical and electrical details; some are faster melting mediums than others; some use less current, etc. These are details that affect the commercial aspect of electric steel, not as a rule the quality of the product and so are beyond the scope of this book.

METHODS OF HEATING BY ELECTRICITY

Heating by electricity may be divided into three classes: (1) Resistance heating, (2) induction heating¹ (3) and arc heating. The first is an important and economical means of making use of temperatures that do not exceed 2,010 deg. F. (1,100 deg. C.)

¹ Properly speaking induction heating is a form of resistance heating. In the latter the heat is generated in a body exterior to the steel or other material being heated while in the former case (induction heating) the resistor is the steel itself.

and is consequently not used in melting. The second class is used to some extent in steel making but is not popular in this country. Table XI, p. 55, notes 3 induction furnaces out of a total of 456 on Jan. 1, 1923. Arc heating, the third class noted above, is the means employed for making practically all of the electric steel now produced.

Resistance Heating.—In heating by resistance, the heat is generated by the opposition offered to the passage of an electric current by a metal, alloy or other substance of suitable resistance. In this class, the laboratory muffle furnace or the carbon combustion furnace is familiar to everyone connected with electric steel making. The heating element may be platinum or a platinum alloy, or an alloy of nickel and chromium. The maximum temperature obtainable is limited by the life of the heating element. Due to the cost, platinum or its alloys is not used commercially and with nickel and chromium the temperature cannot greatly exceed 2,010 deg. F. (1,100 deg. C.) without early destruction of the heating unit.

A notable advance in resistance heating was the development of a furnace using carbon as a heating unit. In this a temperature of 3,100 deg. F. (1,700 deg. C.) or more may be reached. These furnaces are at present only available for steel making in small sizes.¹

Commercially, resistance heating is now used in heat treating furnaces, and very successfully too, especially in hardening operations that demand temperatures of 1,450 to 1,800 deg. F. (790 to 985 deg. C.)

Induction Heating.—If an electrical conductor lies in the magnetic field of another conductor carrying a current, a current will be induced in the second conductor. This is the principle of induction heating and is used to produce enough heat to melt scrap or refine molten charges.

As before stated, induction furnaces are not popular in this country. This is probably due to their disadvantages, the chief of which are: (1) A very high temperature cannot be attained, consequently bath and slag reactions do not take place at the speed desired by the American operator, and (2) it is difficult to operate with cold scrap. If scrap is used, molten metal must be left in the furnace to start the next heat. Because of this

¹ Electrical resistance furnaces have been used for some years in electrode manufacture.

necessity, it is obvious that the induction furnace would not be practical when operation was intermittent or in case of a shut-down over the week end. Induction furnaces are used most successfully to refine molten metal, but even here they offer no advantages over arc furnaces for this class of work. There are other obstacles to the successful operation of induction furnaces, mostly mechanical and electrical, among which may be mentioned low power factor, pinch effect and others which we will not take the time to discuss in detail.

There are two induction furnaces in commercial use, principally abroad, the Kjellin furnace and the Röchling-Rodenhauser furnace. The Kjellin was the original induction furnace. It is built on the transformer principle, the bath of molten metal forming the secondary circuit of a step-down transformer. The furnace is a ring-shaped crucible that holds the charge, lined with refractory materials and surrounded by the primary windings of the circuit. The current induced in the bath is of low voltage and correspondingly high amperage.

The Röchling-Rodenhauser is a similar but improved form of the Kjellin furnace and was designed for use primarily in refining molten metal. Without going into details,¹ it may be said that the superiority of the Röchling-Rodenhauser furnace is that its power factor is much higher and that it can be operated with a current of higher frequency, as high as 60 cycles, compared with only 5 cycles used by the Kjellin.

Arc Heating.—In arc heating the heat is generated in two ways: (1) The metal in the furnace is heated by the radiation from the arc and (2) the heat is obtained by the direct action of the arc on the metal and slag (Figs. 1 to 4). The advantages of arc heating are at once apparent. A high heat, placed exactly where desired is the principal one. In addition, arc heating promotes high electrical efficiency and greatest simplicity of furnace design and operation. The fact that any desired temperature may be attained in slag and metal without extreme localized overheating of the refractory lining makes arc heating the most desirable for steel making.

Heating the metal by the radiation of an arc imposed directly above it is known as indirect or independent arc heating and was

¹ For an extended description of the Röchling-Rodenhauser furnace see RODENHAUSER, "Electric Furnaces in the Iron and Steel Industry," J. Wiley & Sons, 1917.

one of the first means of melting steel electrically. The other method, a direct action of the arc on the metal and slag, the one which is now in extended use is generally spoken of as direct arc heating. The independent arc furnace is not of much importance commercially and will be dealt with briefly; the direct arc, however, will warrant more extended discussion.

CLASSES OF ARC FURNACES

The method of arc heating is given in Figs. 1 to 4 which shows four possibilities. In Fig. 1 the arc is formed between two or

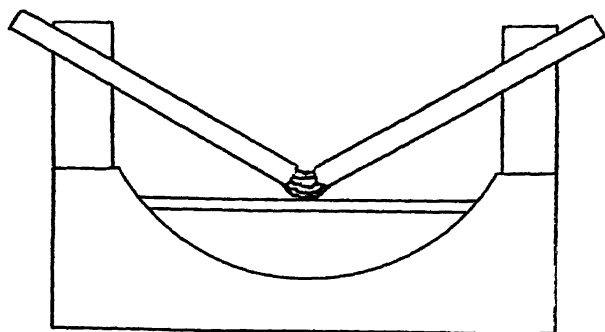


FIG. 1.—Principle of the independent arc furnace.

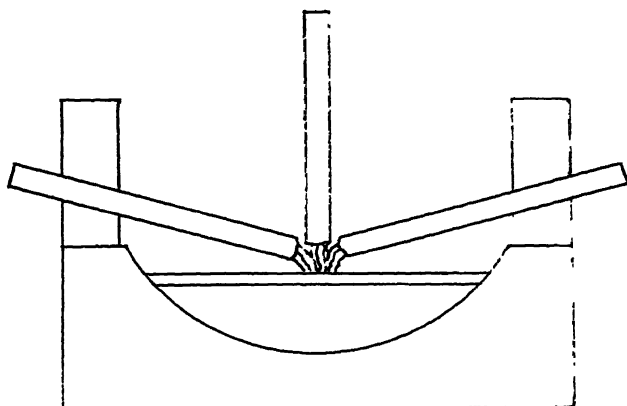


FIG. 2.—Principle of the independent, direct arc furnace.

three carbon electrodes placed above the bath. This is the principle of the Stassano described on page 51. In Fig. 2 the arc from two horizontal electrodes is directed down upon the

charge by a third vertical electrode. This is the method used by the Rennerfelt. Figure 3 is the familiar Heroult principle of the direct arc with a non-conducting hearth, and Fig. 4 shows the

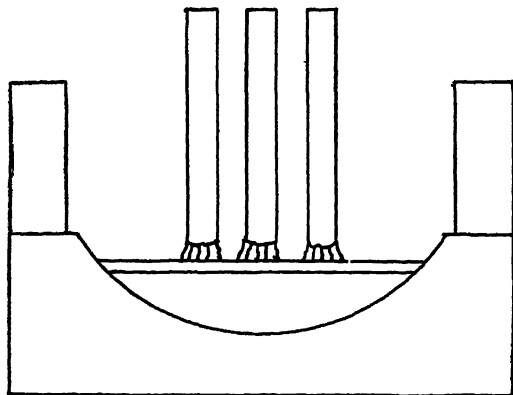


FIG. 3.—Principle of the direct arc, non-conducting hearth furnace.

direct arc, conducting hearth used by the Girod. The four methods of electric arc heating indicated in Figs. 1 to 4 are all used to some extent in steel making.

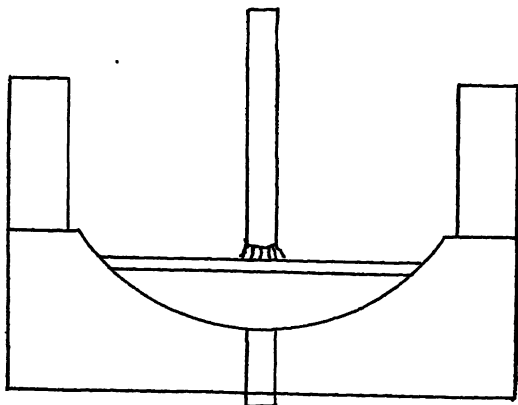


FIG. 4.—Principle of the direct arc, conducting hearth furnace.

In this section, we will view briefly the two forms of independent arc furnaces, noting their disadvantages and why they are not successful in steel making, in this country at least. We will also note the advantages of direct arc furnaces prelimi-

nary to a more extended exposition of these in the next two chapters.

Independent Arc Furnaces.—In the independent arc furnace as we have already seen, the metal and slag are heated by radiation from an arc imposed directly above the bath. The Stassano is of this type, Fig. 5. The furnace consists of a cylindrical steel

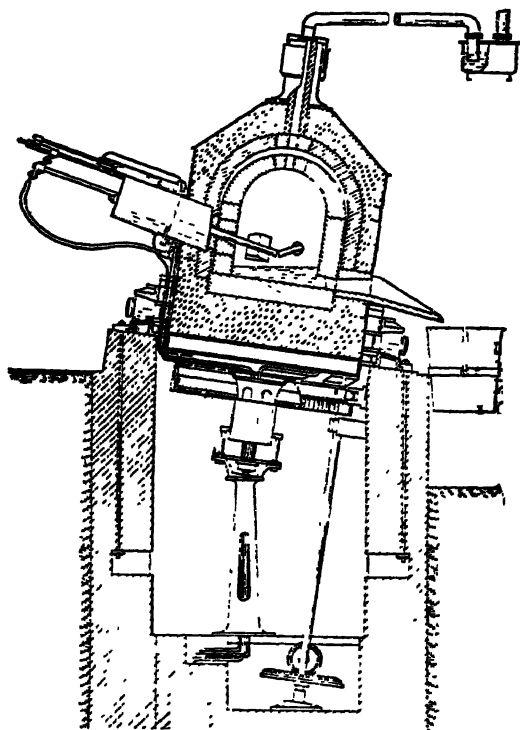


FIG. 5.—Elevation of a 1-ton Stassano furnace.

shell with a circular hearth, lined with magnesite brick. The heat is supplied by the radiation on the metal of the arc between three carbon electrodes introduced into the furnace just above the bath and inclined slightly from the horizontal. The current is 3-phase, 25 cycles, at about 100 volts. Electrode regulation is by hand. Stassano furnaces rarely exceed 1 ton in capacity; in larger units than this temperature conditions in the furnace become uncertain and hard to control.

The Rennerfelt furnace is a cylindrical steel shell with a saucer-shaped bottom lined with basic refractories. Figure 6 shows the general construction and the arrangement of the electrodes. The heat is supplied by three electrodes two of which are horizontal or inclined slightly from the horizontal, and the third let down through the roof vertically. The effect of this arrangement is that the arc from the two horizontal electrodes is directed down onto the bath by the vertical electrode. Rennerfelt furnaces have been built with capacities up to 6 tons. Due to heating and radiation troubles, the Rennerfelt is not used extensively in steel

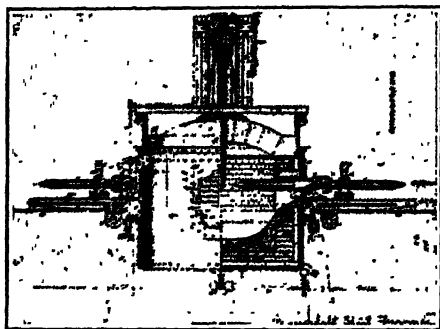


Fig. 6.—The Rennerfelt furnace.

making except in small sizes, being most successful in the melting of non-ferrous alloys. The heating in the Rennerfelt is a combination of direct arc and radiation.

Both Stassano and Rennerfelt furnaces are built on rockers and may be tilted in tapping. By a system of gearing a rocking motion may be imparted to the Stassano while the metal is in the furnace (see Fig. 5).

Disadvantages of the Independent Arc Furnace.—The principal fault of the independent arc furnace as exemplified by the Stassano and Rennerfelt, especially the former, is the localized over-heating that occurs. In the region of the arc the furnace is very hot. As a result, directly below the arc the metal and slag may be greatly overheated while near the banks and bottom the bath will be much too cold. In order to supply sufficient heat to get the bath in condition to tap, the refractory lining and roof become over-heated with correspondingly shorter life. Consequently refractory costs are high.

In addition, heating by radiation is not conducive to rapid refining. It is a known fact, from the results of over a years' experimenting with a 1-ton Stassano at a castings plant¹ in the East, that it is difficult to desulphurize completely. The slag conditions necessary to complete desulphurization are hard to maintain.

Through a system of electrode control by which the horizontal electrodes may be lowered, and because of the vertical electrode, the Rennerfelt may almost fall into the direct arc class. Many of the undesirable features of the Stassano are eliminated by the electrode arrangement in the Rennerfelt; overheating of the bath for example. Even now the Rennerfelt has a high refractory cost. In one installation of 6-ton furnaces with which the author was familiar silica roofs lasted less than 10 heats.² The Rennerfelt has in the past few years become very successful in small units, less than 3 tons, and is one of the best furnaces for melting non-ferrous alloys.

One important operating difficulty with the Rennerfelt and furnaces of the independent arc type is the liability of breakage of the horizontal electrodes. This occurs frequently in furnaces of 3 tons or over. This trouble is so common that many operators of the Rennerfelt have closed the electrode openings in the end walls and put all three electrodes vertically through the roof.

Direct Arc Furnaces.—There are two types of direct arc furnaces both used extensively and successfully in steel making. One type has a non-conducting hearth, the other has a conducting hearth. The conducting hearth furnace is of two kinds. In one the hearth is of regular construction and becomes conducting when heated to a high temperature; in the other, a carbon block, soft steel bars or other conductor is set into the refractories.

Of the direct arc furnaces with a non-conducting hearth, the Heroult is the most popular and has been developed until it is a very efficient steel-making medium. Many modifications have been made to the Heroult and a large number of other furnaces now successful in steel making have been patterned after it. In the conducting hearth type the class having a bottom electrode has not proved successful. The chief disadvantage is trouble with the bottom which seems to develop continually while the

¹ Hess Steel Castings Co., Bridgeton, N. J., 1914-1915.

² This may have been due partly to the furnacemen being somewhat unfamiliar with this type furnace.

furnace is in operation. We will have occasion to touch on this again. The principal furnaces of this type are the Girod, the Gronwall and the Nathusius. Of these the Nathusius has not been introduced into this country, being a German furnace.

Furnaces, the hearth of which becomes conducting at high temperatures, have become practical in the past few years. The Greaves-Etchells is the foremost example of this furnace. A more extended discussion of the Greaves-Etchells will be given later. It is sufficient to say here that it is the only furnace of its class that appears to be practical in sizes exceeding 6 to 10 tons.

Advantages of the Direct Arc Furnace.—The advantages of the direct arc as a heating medium in steel making are numerous. It will be advisable to note them briefly:

(1) A very high temperature may be attained; moreover, this temperature may be reached very quickly.

(2) The amount of heat may be regulated closely, the charge may therefore be brought to any desired temperature and held at that temperature for any length of time.

(3) The direct arc permits any slag conditions to be present, both oxidizing and deoxidizing slags may follow each other in the same heat. In addition slag reactions take place rapidly.

(4) The efficiency is high, most of the heat generated being available for melting or refining.

(5) The heat is even all through the bath; moreover, localized overheating of the refractory walls and roof can be almost wholly prevented.

(6) The load is fairly uniform, making the direct arc furnace a very attractive user to the central station company.

(7) The direct arc furnace is easy to control. Automatic electrode control has made it possible to remove altogether any uncertainty of temperature control from the process.

(8) The direct arc furnace works equally well on cold scrap or hot metal charges; thus the process becomes very flexible.

(9) Details of operation of the direct arc furnace are simpler than any other electric furnace, hence it is not difficult to train furnace labor.

(10) The direct arc furnace is one of the best melting mediums for intermittent operation; particularly for small charges, and in cases where a part of the charge is made into steel of a certain composition, the balance being worked into something different.

(11) The direct arc furnace is the best developed of the electric furnaces. It has, therefore, become more nearly perfect mechanically than any other.

(12) Arc furnaces are not excessively expensive to install and maintain.

TABLE XI.—ELECTRIC STEEL MAKING FURNACES IN THE UNITED STATES AND CANADA¹

Furnace	Capacity	Number	Totals
Heroult	Less than 6 tons	73	
	6 to 10 tons	95	
	10 tons or over	13	181
Snyder	All 6 tons or less		53 ²
Rennerfelt	All 3 tons or less		18 ²
Greaves-Etchells	Less than 6 tons	20	
	6 to 10 tons	5	
	10 tons or over	3	28
Gronwall-Dixon ²			12
Ludlum	Less than 6 tons	6	
	6 to 10 tons	8	14 ²
Girod	Less than 6 tons	4	
	6 to 10 tons	1	5
Booth ²			10 ²
Moore ²			53 ²
Induction furnaces ²			3
Webb ²			2
Stassano	1 ton		1
Greene	All 3 tons or less		27
Vom Baur	One 8 tons, others less than 6 tons		5
Detroit	All 1 ton		3
Volta ⁴	6 tons	9	
	Less than 6 tons	4	13
Special, etc. ²			28
Total, United States.....			406
Total, Canada.....			50
Grand total.....			456

¹ Statistics furnished by *Iron Age*, New York

² Capacity not available for publication.

³ Not official.

⁴ The Volta is a Canadian furnace, only 2 in the U. S.

The direct arc furnace has become so thoroughly developed that it exceeds all others in installations; in this country at least, by nearly 500 per cent. Table XI gives the total furnaces installed or contracted for on Jan. 1, 1923. Nearly half of the furnaces, and considerably more than half of the tonnage, is the product of the Heroult, while the Heroult, Greaves-Etchells, Ludlum, Vom Baur and Volta produce probably more than 90 per cent of the electric steel ingots. All of these are direct arc furnaces.

Summary.—In the foregoing pages we have discussed the three types of electric heating and have seen that the electric arc is the only medium that has been an unqualified success in steel making. We have consequently dismissed resistance and induction heating and will hereafter confine our description of the melting process to furnaces of the arc type. We have further distinguished between the two classes of arc furnaces, and after having described briefly the Stassano and Rennerfelt, have seen that the independent arc as typified by these two furnaces has not been practical in American practice. We may make an exception of the Rennerfelt because in small units it has been, and is being operated successfully.

Having noted that arc furnaces are the most practical steel making mediums and that the direct arc is the best of the two classes of arc furnaces, we will dismiss the independent arc and concentrate on the direct arc. The next step, therefore, is a description of the method of introducing the current into the furnace and by means of this current producing the heat necessary to melt and refine the charge. Two divisions of this description naturally present themselves: (1) The power supply, (2) the electrodes.

POWER SUPPLY FOR THE ARC FURNACE

The Electric Current for the Direct Arc Furnace.—The arc furnace demands for its operation a current of low voltage and high amperage. In most plants the current used is brought in by high tension feeders carrying up to 13,000 or more volts. Two sets of transformers are used, one for the plant generally and the other for the furnaces. Six-ton Heroult furnaces of the older type have two transformers for each furnace; in recent installations only one transformer is used. The current delivered to the

furnace is about 10,000 amperes for each phase and is at 90 to 100 volts.

Using cold scrap the current consumption of a furnace is from 700 to 750 kw.-hr. per ton of ingots.¹ On the hot metal furnaces it is much less, ranging from 100 to 200 kw.-hr. All of the current from the transformer is not available for heating. Due to the fact that alternating current must be used in electric furnace work, there will always be a difference between the total power (watts) that should be delivered to the electrodes at any one instant and the actual effective watts delivered. Any inductance effect in the circuit causes a slight difference in phase between the voltage and amperage, the amperage will then tend to lag behind the voltage, consequently, both do not reach the maximum at the same moment. The ratio of actual effective watts to total watts is the power factor. When conditions are good, as they are on recent furnace installations, the power factor is about 0.90. A high power factor is so important that central station companies insist that electric furnaces maintain a factor in excess of 0.70.

Electric Furnace Power Supply.—The power for electric furnaces is, as a rule, supplied by central station companies; in only a few plants is current generated by steam from boilers fired with blast furnace gas, available. The question of steady and cheap power for an electric steel plant of three to six furnaces presents a problem in economics that is demanding the attention of some of the foremost steel electrical engineers of this country. To operate successfully, the electric furnace must run continuously night and day, 6 days a week and 52 weeks a year. This means that the electric furnace is demanding a heavy supply of power just at a time when the other load on the central station is the heaviest; in other words, the electric furnace must operate during the peak period as well as in the power station's dull period. Therefore, expensive generating machinery must be kept in readiness to handle all of the demand of the peak period, while at other times it may be idle. This results in the electric steel plant paying a heavy demand or standby charge, which goes on whether the furnaces are operating or not, and which is one of the biggest factors in keeping up power costs.

An electric furnace melting cold scrap has considerable, sometimes violent, fluctuations in load during the melting period.

¹ Average over a 5-year period. This figure is per ton of ingots produced.

This is an additional cause for the high standby charge that the electric steel company must pay. In plants operating more than one furnace, a reduction in the standby charge often results from preventing all of the furnaces from melting down at the same time. Thus if a plant has two furnaces, one is refining while the other is melting. While this sometimes tends to slow up furnace operations, it will in most cases reduce power costs effectively, although it is a very difficult matter in practice to dovetail the high melting demands and low refining demands. These fluctuations are only present with cold scrap melting, the larger hot metal furnaces do not have this disadvantage.

Electric furnaces operate with currents having frequencies of either 25 or 60 cycles; 25 cycles is the most common, as it permits a greater power input to a furnace than 60-cycle energy. This is due to a lower magnetic loss and the decreased heating and inductive effects of the higher periodicity. In general, a better power factor is obtained with 25 cycles than with 60.

Importance of the Cost of Power.—The power cost question is one upon which the whole future of the electric steel industry depends. At present power costs are so excessive that except in very prosperous times the electric furnace cannot even partly compete with the open hearth in the manufacture of the more common alloy and tool steels. In fact, to compete seriously in anything but the very high grade steels, power should be considerably below its present average figure of 1.5 cents; it should even be less than 1 cent. This is particularly true in the cold scrap process that has excessive power consumption in the melting period.

Up to the present time, users of alloy steels have not been educated to the possible superiority of electric steel. This is very noticeable in the automotive industry where only a few of the higher priced motor cars use steels from the electric furnace. This is due almost wholly to their additional cost. Power for a 6-ton heat melted from a scrap base will average close to \$10 per ton, rarely getting below \$6. Compared with the fuel cost in the open hearth, these high electric power costs impose a severe handicap on the electric process, especially in the smaller units.

Power companies that have a large excess of hydro-electric power will often offer the electric furnace plant attractive rates, but only if this water power is available all of the year. It

seems probable that most future electric furnace installations will be made where hydro-electric power is plentiful, particularly in the Southern part of this country where it would be available all of the year.

Introducing the Current into the Furnace.—Furnace transformers are always located close to the furnace. This is necessary

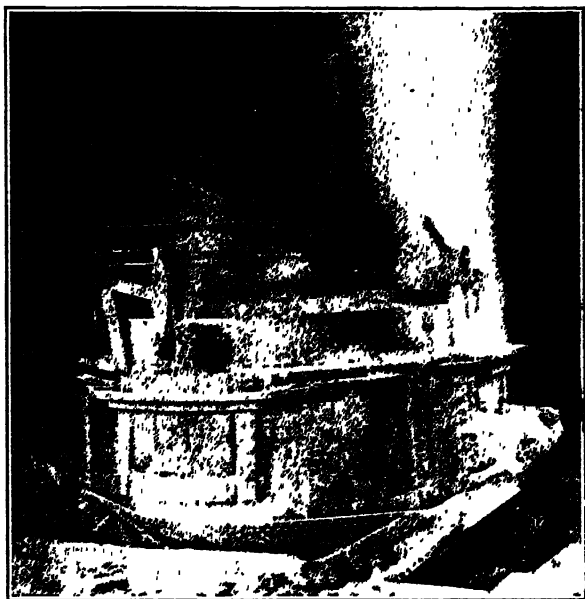


FIG. 7.—Side view of a 6-ton Heroult furnace—old type.

so that the costly low-pressure leads may be as short as possible. The low-pressure leads which carry the current from the transformer house, directly behind the furnace, to the copper bushars that lead to the electrode holders are 1 to 1½ in. copper strand. The leads of the different phases are symmetrically placed with reference to transformers, are of sufficient length to allow for tilting the furnace, and are suitably insulated from each other. In modern furnaces, the leads are brought from the transformer house to the furnace underground.¹ See Fig. 16, p. 83.

The busbars are of solid copper and extend horizontally from the vertical framework at the back or side of the furnace

¹ With the latest hot metal furnace the leads are not underground. See Fig. 18.

to the electrode holders. In Fig. 7, the arrangement of the busbars is clearly shown. This is one of older type Heroult furnaces installed in 1916. The connection of the busbar and electrode is made by a steel and copper holder, the two metals being suitably insulated from each other. In Fig. 7, the holder is shown grasping the electrode just above the roof. A tight fit for the holder is made by a screw in front of the electrodes. Above the copper electrode holder is the steel holder connected by a horizontal steel channel with the control mechanism at the back or side of the furnace. In Fig. 13, p. 80 and Fig. 16, p. 83, the arrangement of the electrode holders is again clearly shown.

From the holder the current is led to the bath by the electrodes which may be either amorphous carbon or graphite. Both types have been developed greatly in the past ten years and will be discussed in detail.

ELECTRODES¹

Electrodes for the direct arc furnace are usually three in number, and in the majority of types are introduced into the furnace through the roof at the vertices of an equilateral triangle. In some recent furnaces which are oval-shaped, they are arranged in a line instead of the triangle. Some of the older furnaces of small capacity were single phase and had only one electrode. Better operation has been secured by three-phase current so lately all furnaces of 1 ton or over have three electrodes.

Carbon Electrode Manufacture.—Electrodes for direct arc steel-making furnaces are always round in cross-section, vary in diameter from 5 to 24 in. and are about 5 ft. long. At present all electrodes are threaded at both ends for continuous feeding. The manufacture of both carbon and graphite electrodes is essentially the same, the process of graphitization being a continuation of the manufacture of the amorphous carbon variety.

The raw materials are anthracite coal, petroleum coke and a binder, such as pitch or tar. Before being used the anthracite coal is calcined until less than 0.5 per cent volatile matter remains. After calcination the coal and coke are ground, mixed in the proper proportion, heated and the binder added, and finally molded and pressed. Correct mixing is very important and is necessary for a high quality in the resulting electrode. After

¹ The author wishes to acknowledge his indebtedness to S. L. Walworth of the Acheson Graphite Co., and to F. J. Vosburgh of the National Carbon Co., for much of the information on electrodes contained in this section.

pressing they are baked at a temperature of 1,925 to 2,000 deg. F. (1,050 to 1,100 deg. C.); formerly in electric resistance furnaces of the Acheson type; more recently in gas-fired regenerative furnaces. Heating takes from 12 to 20 days, cooling about the same length of time.

After baking is completed the amorphous carbon electrodes are cleaned, machined and threaded. Large electrodes, such as are used with furnaces of 3 tons or over, are drilled and tapped on both ends and nipples provided for joining. Small electrodes are drilled and tapped on one end and threaded on the other.

Graphite Electrode Manufacture.—Graphite electrodes are made by putting the amorphous carbon electrodes through a graphitization process, whereby all of the carbon is changed to graphite. This procedure consists of heating the carbon electrodes in an electrical resistance furnace to 3,630 deg. F. (2,000 deg. C.) and holding at this temperature for 4 to 6 days. The additional cost of graphite electrodes is mainly a cost of graphitization, as it takes from 3 to 5 kw.-hr. per pound of graphitized carbon.

The process of graphitization is supposedly as follows: The amorphous carbon forms carbides with the oxides present as impurities in the ash. These carbides are decomposed at the high temperature to graphite, the impurities being volatilized. After graphitization, the furnace is cooled slowly, 20 to 30 days being necessary. The electrodes are then machined similarly to the carbon electrodes described just above.

Natural graphite is not used for electrodes as its cost is excessive and because the graphitized carbon produces a product superior in every way to the natural graphite.

Method of Joining Electrodes.—Electrodes for steel-making furnaces are now all threaded for continuous feeding; nipples of the same composition being supplied with the electrodes, together with a paste or electrode compound, in the case of carbon electrodes, for making a tight joint. To place a new electrode in position, a hoist pin is screwed into one end of the electrode, after which it is hoisted by a crane, Fig. 8, and brought to the furnace. Electrode paste is liberally applied into the threaded cavity of the electrode already in the furnace with graphite electrodes no paste is used) and the nipple screwed into the upper end of the electrode until it is firmly seated against the bottom of the hole. The new electrode is then spotted

directly over the nipple, Fig. 9, and after applying paste to the exposed portion of the latter, is screwed down on the nipple as far as possible by hand as the electrode is slowly lowered by the crane. An electrode wrench is then slipped over the new electrode and tightened. With one or two turns the upper electrode is screwed down tight, Fig. 10. Sufficient paste should be used so that some excess squeezes out when the new electrode is in place.

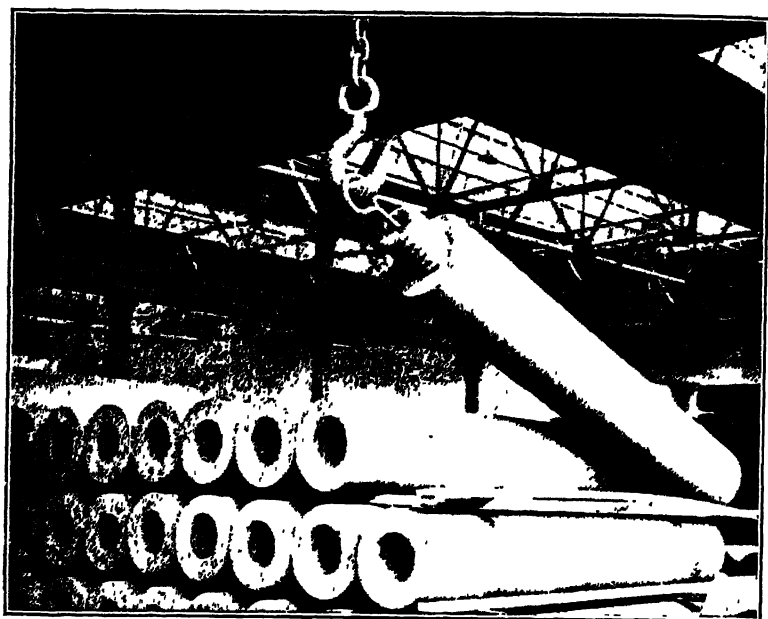


FIG. 8.—Transferring electrode from pile to furnace.

As before noted, graphite electrodes do not need any joint compound, the higher conductivity of the graphite is sufficient to offset any slight resistance at the threaded joint. With amorphous carbon, unless the nipple and threaded ends of both electrodes are well daubed with the paste, the resistance of the imperfect joint may be sufficient to raise the electrode to a red heat. At this temperature oxidation occurs quickly, leading to rapid deterioration and probable breakage.

Amorphous Carbon Electrodes.—Amorphous carbon electrodes may be used for every type of direct arc furnace. They

are all 5 ft. long and vary in diameter depending upon the amount of current to be carried; in other words depending upon the size of the furnace. For the 1-ton the 8- or 10-in. is used; $1\frac{1}{2}$ to $2\frac{1}{2}$ tons take 10- or 12-in.; 3-ton, 14-in.; 6-ton, 17-in.; 10-ton, 20- to 24-in.; and the large hot metal furnace, 20 to 35 tons, 24-in.

The amorphous carbon electrode is the strongest. For that reason it is favored for the cold scrap furnace where it gets the



FIG. 9.—Placing electrode in position. FIG. 10.—Screwing electrode into place

roughest usage. The advantage that is probably of the greatest importance to the steel maker is the cost. Carbon electrodes are more reasonable both in first cost and in cost per ton of steel produced than graphite,¹ although the consumption is much greater. In this, the amorphous carbon will average 30 to 40 lb. per ton against 15 to 18 lb. of graphite for basic steel from cold scrap. In acid practice, the consumption of carbon is 15 to 25 compared with about 10 lb. of graphite electrode. In duplex-

¹ Recent figures from a 6-ton basic furnace making castings showed that graphite electrodes averaged less than amorphous carbon, per ton of steel made. John H. Hall, private communication, May 15, 1923.

ing, consumption is about the same as in acid practice, 18 to 25 lb. for amorphous carbon and 9 to 10 lb. for graphite.¹ In general, the carbon electrode consumption will be a little more than twice the graphite consumption.

Another feature that makes carbon electrodes favored, is the lower thermal conductivity; they conduct less heat away from the furnace than graphite, but, in this connection, it should be remembered that although the graphite electrode will conduct more heat per unit area, it is only half the size of the amorphous carbon electrode.

Graphite Electrodes.—Graphite electrodes have four times the conductivity of amorphous carbon, thus an electrode only half the size will carry the same current. This is an especial advantage in the large furnace where three holes each at least 24 in. in diameter may weaken the roof and thus shorten its life. On 1- and 2-ton furnaces 5-, 6- or 7-in. electrodes are used; on 3-ton, 8- or 10-in.; and on the 6-ton the size necessary is 9- to 12-in. The larger hot metal furnaces take a 12-in. for the 25-ton and a 14-in. for the 30-ton furnace.

The higher cost of graphite electrodes has restricted their use in steel-making furnaces especially in the smaller sizes where they offer no advantages over the amorphous carbon. They are, however, used somewhat extensively in hot metal furnaces.

Graphite oxidizes at a very much higher temperature than amorphous carbon. This serves to make consumption less than half that of carbon and in addition—this is important in many cases—serves to prevent excessive penciling at the lower end, which fault is common with amorphous carbon electrodes. Because of its high electrical conductivity, no paste is necessary at the joint and of course, possibility of high resistance at this particular spot is reduced to a minimum. Since the resistance here is never excessive, oxidation and frequent breakages caused by the joint becoming red hot do not occur. This is a notable advantage because even with the greatest apparent care joint trouble is frequent with the carbon electrode. Whether electric steel plants admit it or not, a walk through the melt shop will always bring to light broken chunks of electrodes and examination of furnace log sheets over periods of time will show more than one case of delay from the same cause. Another disadvantage of

¹ These figures represent average conditions with no economizer used.

the easily breakable electrode joint, a disadvantage probably never mentioned heretofore but well known in every melt shop, is the wear and tear on the disposition and feelings of the furnacemen who must rake a 50- to 200-lb. chunk of electrode out of the bath before an appreciable amount of carbon is absorbed by the metal and the heat spoiled. And it usually occurs just before tap too!

Graphite versus Amorphous Carbon Electrodes for Steel-making Furnaces.—The advantages and disadvantages of the two kinds of electrodes may be briefly summarized:

The advantages of the graphite electrode are:

(1) Higher conductivity, four times that of amorphous carbon, permitting smaller electrodes to be used.

(2) No heat nor current losses through the joint. A tight joint can be made without the aid of an electrode compound.

(3) The use of smaller electrodes results in greater strength of the roof.

(4) Graphite electrodes do not oxidize so easily, the consumption is a little less than half that of amorphous carbon.

(5) Graphite electrodes being half the size do not need as heavy control mechanism as the amorphous carbon.

(6) Transportation cost is only half that of amorphous carbon.

(7) If an electrode breaks and falls into the bath, it is less trouble to remove the piece than is the case with the amorphous carbon.

The disadvantages of the graphite electrode are:

(1) They are much more costly than amorphous carbon.¹

(2) They are more fragile.

(3) The higher heat conductivity of graphite electrodes produces greater heat loss than occurs with amorphous carbon.

(4) If breakage occurs in transportation or handling, the loss is greater with graphite electrodes.

The advantages of amorphous carbon electrodes are:

(1) They are cheaper than graphite.

(2) They are stronger than graphite.

(3) Provided a good joint is made at the threaded connection, the heat losses through the amorphous carbon electrode are less than through the graphite.

Their disadvantages are:

¹ This is cost per pound. They may not be more costly per ton of steel. See note bottom p. 63.

- (1) They have lower conductivity.
- (2) They oxidize easily.
- (3) Great care must be used in making a tight joint at the threaded connection or excessive heat losses, current losses and breakage will occur.
- (4) Due to their size the transportation cost is higher than with graphite electrodes.

From the above and from noting the number of electrodes in actual use, it may be said that from an electrical standpoint graphite electrodes are the best but their greater fragility offsets the advantage of smaller size. As far as cost per ton of steel made is concerned, there is probably little difference between amorphous carbon and graphite. Taking all factors into consideration graphite electrodes give more satisfactory service on furnaces of less than 1 ton and more than 15 tons capacity, and amorphous carbon give the best satisfaction on the intermediate sizes including the 6-ton.

Soderberg Continuous Electrode.—Before leaving the subject of electrodes, we will dwell briefly on the subject of the Soderberg continuous self-baking electrode. This is one of the notable advances in electric furnace practice in the past few years, and although it has not, to date, been used with success on steel-making furnaces, it seems worth while to describe it briefly. Up to the present time, it has been used principally on stationary furnaces, those ferro-alloy furnaces of the open top type particularly. It is very possible that either this electrode or some modification of it may in time be developed and applied to tilting steel furnaces.

The electrode shell is a sheet-iron casing of small gage having ribs extending radially into the center. The electrode mixture is about the same as is used for ordinary amorphous carbon electrodes, *i.e.*, ground and calcined anthracite coal and petroleum coke with a tar or pitch binder, and is tamped firmly into the metal shell. As the electrode is slowly fed downward, the green mixture becomes baked from the heat of the furnace and from the internal resistance to the current so that the part below the holder is a solid mass of carbon enclosed in a steel jacket. When the electrode becomes short, a new section of casing is welded on and filled with the mixture. The mixture in the old electrode is still soft on top and mixes thoroughly with the contents of the new section.

The advantages are principally economy and freedom from electrode breakage. The casing protects the electrode and prevents excessive oxidation. The disadvantages as applied to steel-making furnaces are numerous and at the present time apparently unsurmountable. In the first place it is a difficult job to weld a new section of casing unless a permanent platform is constructed above the furnace roof. This platform is also necessary in tamping in the electrode mixture. The long section of newly welded electrode is very heavy and would be compelled to stand considerable strain when the furnace was tilted.

The continuous self-baking electrode has many advantages and has proved successful when used on ferro-alloy furnaces; it is economical, has better conductivity, less heat loss and oxidation and, in addition, has the great advantage that it makes the steel plant independent of shortage, delays and other difficulties in securing electrodes promptly. In view of these advantages, it seems probable that the continuous self-baking electrode, or the principle at least will be developed until it can be applied successfully to the tilting steel furnace.

Electrode Control.—All direct arc furnaces, at least all furnaces exceeding one ton in size, are now equipped with automatic electrode control. This apparatus consists of a motor connected by a steel cable to each electrode holder (see Fig. 14, p. 82) by which the electrode may be raised or lowered; the distance depending upon the amount of current supplied and the length of the arc desired.

For descriptive purposes and because it is representative of the latest development, we will describe the General Electric automatic electrode control for the direct arc furnace. The necessary regulators, current indicators and switches are placed on panel boards of which the one shown in Fig. 11 is representative. These regulators control the motor movements and raise and lower the electrode to keep the arc at a definite length thus keeping the amount of current passing through the electrodes constant with a resulting constant temperature. To explain the manipulation and resulting movement of the electrodes, we will first hypothetically lower and then raise the temperature.

With the throw-over switch set in automatic control, we now move the three regulating rheostats a definite number of divisions. The raising contactors (Fig. 11) are automatically thrown in, the lowering contactors if in, are thrown out at the

same time, and the motors start at once winding up the cable until the arc is at such length that the current delivered is in balance with that determined by the regulating rheostats and shown on indicating ammeters (not shown in Fig. 11). This length of arc and delivery of current is then maintained until we

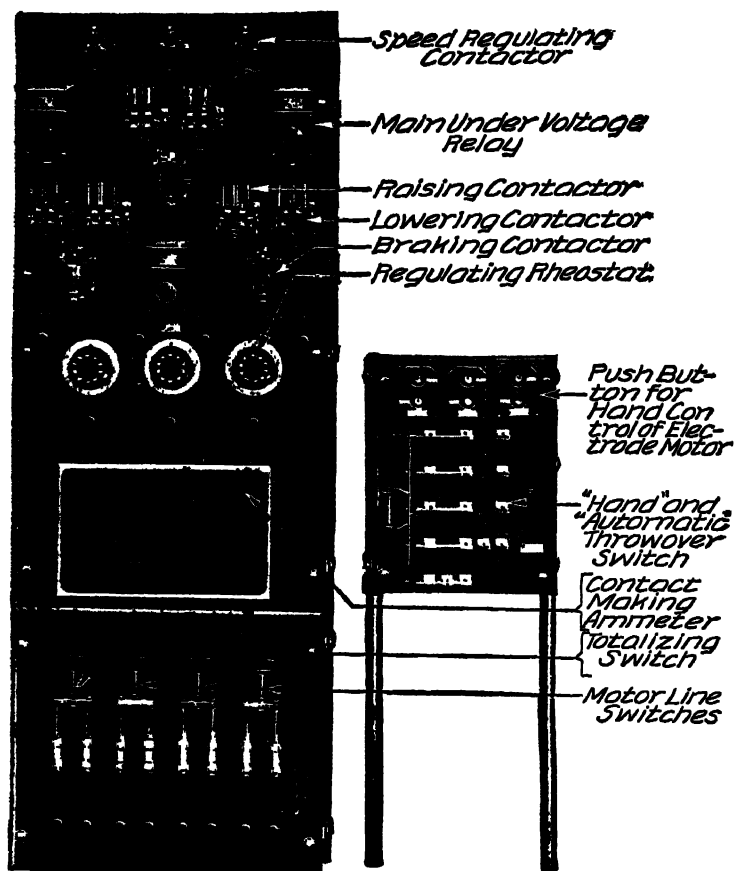


FIG. 11.—Panel board for 6-ton Heroult furnace, General Electric Co.

desire to change the temperature. The rheostats are moved a few divisions increasing the current input. The three contact-making ammeters (Fig. 11) actuate the braking contactors resulting in the raising contactors being thrown out and the lowering contactors thrown in. The motors reverse and the electrodes lower until the current is again in balance and equal to that

determined by the regulating rheostats and shown on the three indicating ammeters.

Thus when the regulating rheostats are set on the points determining a definite current input as measured by the length of the arc and shown on the ammeters, the raising, braking and lowering contactors adjust themselves, controlling the motor movements and, regardless of internal conditions in the furnace, keep the arc at a fixed length, resulting in a constant temperature indefinitely.

To operate the electrodes by hand, the main throw-over switch is reversed; if the upper push buttons are held in, the electrodes will raise, conversely the lower push buttons lower the electrodes.

The automatic electrode regulators shown in Fig. 11 are manufactured by the General Electric Co.; are the simplest, best and easiest control for electrodes yet developed and are standard equipment on nearly all direct arc furnaces.¹

THERMAL EFFICIENCY OF THE DIRECT ARC FURNACE

Compared with other melting furnaces, the thermal efficiency of the direct arc furnace, especially of the Heroult and allied types, is high, averaging at least 65 per cent, often 75 per cent. Lyon and Cullen² give the following efficiencies of the ferrometallurgical operations:

	PER CENT
Blast furnace	Average 60
Acid open hearth	Average 12
Basic open hearth	Average 10
Crucible	Average 4
Direct arc furnace	Average 70

There are several ways in which heat is lost in the direct arc furnaces. They are: (1) Electrode losses, (2) door losses and (3) lining losses. All are important, the first, however, is the source of most of the loss. Since the introduction of the economizer, the heat loss due to the oxidation of the electrodes has been greatly reduced. The second and third are variable and depend largely upon the furnace practice used.

Heat Loss through and around Electrodes.—The loss through and around the electrodes includes the heat lost by the thermal

¹ Equally efficient regulators are manufactured by the Westinghouse Electric Co.

² LYON, KEENEY and CULLEN, *The Electric Furnace in Metallurgical Work*, Bureau of Mines, *Bulletin 77*, p. 4, 1916.

conductivity of the electrode, the heat lost between the electrodes and the cooling rings and by electrode oxidation. The heat lost through the space between the cooling ring or collar and the electrode is the principal one. This has been investigated. It was found¹ that the rise in temperature of the water circulating through the cooling rings was 22 deg. C. for 428 gal. per second equal to 10,000 calories or about 40 kw. The sum total of the heat in the cooling water was 120 kw. Since 650 kw. was supplied to the furnace, this loss is 18.7 per cent of the power used. About 85 per cent of this loss is through the roof rings, and 15 per cent through the electrode holders. At least 15 and probably 20 per cent of the current introduced into the furnace is carried away by the water circulating through the cooling rings. This cannot be greatly reduced. Water cooling is very essential if electrode holders and other metal parts are not quickly destroyed. It is also very essential to prevent undue heating of the roof refractories which become conductors at high temperatures and thus may waste current. It also prevents excessive electrode oxidation. This brings us to the subject of the electrode economizer.

The Electrode Economizer.—The electrode economizer is a device so constructed that the sensible heat of the gases escaping between the electrode and cooling ring is removed before it strikes the air and thus becomes oxidizing. One form is shown in Fig. 12 which is self-explanatory.² As Fig. 12 shows, the device consists of a water-cooled ring which fits around the electrode directly above the furnace roof.

Quoting from the Electric Furnace Construction Co.'s booklet:

While the gases are inside the furnace, they are under reducing conditions, and have therefore only their own sensible heat and no heat generated by combustible constituents. These gases first pass in between the electrode and port hole of the roof, and then through a clearance in the cooling ring, and an expansion of the gases thereby gives up a large amount of their sensible heat. This heat is absorbed by the water in the cooling ring. From this chamber the gases pass through a small clearance and then enter a very large chamber for a second and much greater expansion. This chamber is surrounded with a thin

¹ M. R. WOLFE and V. DEWYCKI, *Trans. Am. Electrochem. Soc.*, xxxviii, (preprint), 1920.

² Figure 12 and description by courtesy of the Electric Furnace Construction Co., Philadelphia, Pa.

enclosed cover, which in actual practice has been found quite sufficient to dissipate the heat given up by the gases; and when they finally pass through the last clearance, they will not ignite when they meet the oxygen of the air. This very largely prevents the chimney effect and the rapid burning away of the electrode—and prevents tapering at the point of the arc.

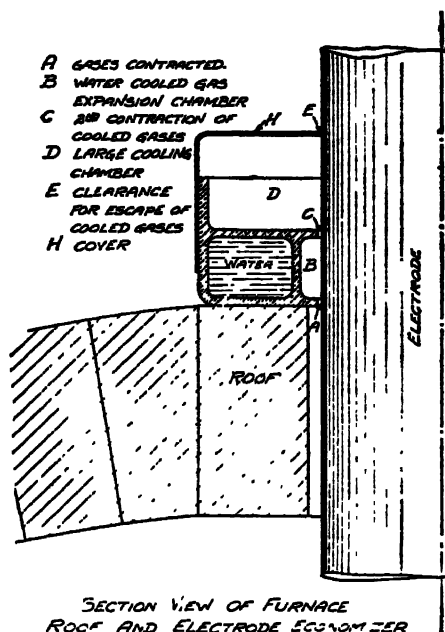


FIG. 12.—Sectional view of furnace roof and electrode economizer. (Patent applied for).

In cases where economizers are not used, the air going through the furnace doors strikes the white hot electrode, the roof openings act as chimneys, and the electrode burns away and pencils off.

When oxidation of the electrode is restricted, especially the oxidation that causes penciling on the end, heat losses are also restricted and power saved. Thus the economizer not only reduces electrode consumption but also reduces heat losses and thus serves to increase the thermal efficiency of the furnace.

Heat Losses Caused by Open Doors.—It is very important in electric melting practice to keep doors as tight as possible. Much power could be saved, much oxidation of electrodes prevented, with resulting increased efficiency and faster heats, if

furnace doors were better constructed and kept tightly closed. In this the furnace builder is not so much to blame as the melter. The cracks and cavities between the door and sill may be luted with fireclay, and—this is the greatest cause of the trouble—doors may be kept closed by the furnaceman. There is no excuse for the frequent and unnecessary opening of doors as practiced by ninety nine out of every hundred melters. The average melter seems to think it is essential to the quality of his steel that he looks into the furnace every few minutes, not realizing that atmospheric oxygen might harm greatly the carbide slag and cause excessive oxidation of the electrodes with great waste of heat and power. Every time the door is opened an inward sweep of air occurs, the space between the electrodes and the cooling rings, serving as a chimney and thus, unless an economizer is used, oxidizing and penciling the electrode to a point on its lower end. A tight furnace is conducive to economies in both electrode and power consumption and, in addition, refining reactions in the final period are facilitated.

Heat Losses through the Lining.—We have had occasion to speak of this before (see p. 21). There is at present much discussion as to whether it is more economical to use a thin lining with increased heat losses, but with less chance of overheating refractories, than to use a thicker or better insulated lining and take chances of localized overheating causing premature failure of the brickwork. Heat losses through the lining can be almost wholly prevented. One course of firebrick, or a 1- or 2-in. space filled with silo-cel or other insulator, will keep the furnace shell almost cold.

If the insulating part of the lining is omitted, and this is becoming a more common practice, the heat dissipated through the lining and shell may amount to 5 or 6 per cent, sometimes more, of the total current input. There is much to say on both sides of this question, it will probably remain undecided for some time.

Preventing Heat Losses in the Direct Arc Furnace.—We may summarize briefly: We have three sources of heat losses; electrode, door and lining; the first being by far the most serious. At least 18 per cent of the power input is carried away in heat absorbed by the water circulating through the cooling rings and electrode holders. This cannot be much reduced. A small amount, this should not exceed 2 per cent, is lost through thermal

conductivity of the electrodes. This loss is less with amorphous carbon than with graphite. In addition a small amount of power is wasted by the resistance of the electrodes and through eddy currents. By use of economizers, and through better fitting doors, and care on the part of the melter, heat losses through doors and because of electrode oxidation and penciling can be greatly reduced. This should not exceed 5 per cent of the power input. With care it may be made less than this. Heat loss through the lining is, as we have seen, variable and depends on the practice used.

Thus we see that a direct arc furnace will have irreducible heat losses equivalent to 20 to 25 per cent of the power delivered to the electrodes. By care, the other sources of loss, except lining losses, should be considerably less than 5 per cent. By using economizers and through ordinary care in operating, the furnace should be at least 75 per cent efficient.

CHAPTER IV

THE HEROULT FURNACE

The 6-ton Heroult Furnace—The 30-ton Heroult Furnace

The Heroult is the most popular of the electric steel-making furnaces. It leads all others in installations; more than half of the larger size furnaces, six tons and upwards are Heroult. At least 65 per cent, perhaps 75 per cent of the electric steel ingot tonnage is produced in this furnace. Until recently it was the only furnace of which sizes ranging from 15 to 35 tons were successful. Although the Heroult has many faults, principally mechanical, and although there are perhaps faster melting furnaces now constructed, furnaces operating more rapidly and cheaply on both hot metal and cold scrap, it is the best known furnace and so will be described in detail in the present chapter. Most of the recent successful direct arc furnaces are adaptations of the Heroult, following its principle and most of its construction details. These furnaces will be described briefly in the next chapter.

The present Heroult furnace was invented by Paul Heroult in 1900. The patent taken out stated that to avoid carbon absorption by the molten bath the slag used to refine the metal should be inserted between the metal bath and the electrodes. Heroult, in his first efforts, used a bottom electrode, but as it was not successful turned to the arrangement used today of the electrodes in series and a non-conducting hearth. As developed by Heroult, and applied to steel making, his was the first successful attempt at melting and refining by the direct arc in a furnace with a non-conducting hearth.

Heroult furnaces are built in a wide range of sizes. For cold scrap the common capacity is 1 ton, 2 tons, 3 tons, 6 tons, and possibly 10 tons; for refining hot metal, 15 tons, 20 tons and 30 tons. The most common are the 6-ton and the 20-ton sizes. In practice most Heroult furnaces are overcharged, usually 10 to 25 per cent, sometimes as much as 50 per cent.

For descriptive purposes we will take up in this chapter the 6-ton furnace, tapping from 14,000 to 16,000 lb., as typical of the cold scrap furnace. In describing the large hot metal furnaces particular reference will be made to the 30- to 40-ton furnace installed at the U. S. Naval Ordnance plant. This furnace, which we will speak of as the 30-ton furnace, although it ordinarily produced from 75,000 to 95,000 lb. of ingots, represents the latest installation of a large capacity Heroult.

THE 6-TON HEROULT FURNACE

The 6-ton Heroult furnace illustrated in Fig. 7, p. 59, Fig. 13, p. 80 and Fig. 14, p. 82 is essentially a steel shell with a nearly flat or, in the older types, a slightly rounded bottom also of steel plates. The shell has one or two working doors and a tapping door or spout. At the back of the older furnaces or at the side in the later construction, Fig. 16, is placed the vertical steel work supporting the electrode holders and control mechanism. The slightly arched refractory roof is pierced by three holes through which the electrodes are introduced into the furnace. On the roof, and fitting closely to the electrodes with just sufficient room for a vertical movement through them, are the electrode rings or collars through which water circulates constantly (see Fig. 13). Above the electrode ring and movable in a vertical plane, is a holder for each electrode also water cooled. The electrode holder is connected by steel channels to the framework at the back or side of the furnace. The up-and-down movement of the electrodes is controlled by individual motors and is regulated automatically as described in the previous chapter. Supplementing this general description, we will now take up the furnace in detail.

The Furnace Shell.—The construction of the furnace shell is shown clearly in Fig. 7, p. 59 and Fig. 32, p. 138. Figure 7, p. 59, represents the older and more common construction used on furnaces installed in 1915 to 1917. Figure 32, p. 138, shows the later models. The late type with a cylindrical shell and nearly flat bottom is the best construction especially when combined with the newer tilting mechanism. It will be noted from the above illustrations that the Heroult resembles, in many features, the tilting open hearth.

The shell is about 12 ft. in diameter which allows between 8 and 10 ft. clearance when lined. It is constructed of steel plates

about $\frac{3}{4}$ in. thick riveted together and riveted to the bottom. The ring holding the slightly arched roof sets flush with the top of the shell and is fastened to the latter by adjustable bolts.

Doors.—The shell is pierced by a tapping door and by one or two working doors. When the electrode mast is directly behind the spout, Fig. 7, p. 59, there are two doors, one on the left and one on the right side of the furnace. With the mast to one side, Fig. 16, p. 83, there is only one door, directly opposite the spout through which charging and working are carried on during the heat.

The tapping door and spout on the older furnaces are of the design shown in Fig. 7. This arrangement has been replaced by one with a skim-gate illustrated in Fig. 15 which allows the metal to be tapped free from slag. It was soon seen that the older door design was not suitable as the steel and slag were tapped together and mixed in the ladle. Most of the old style doors have been replaced with a construction similar to that in Fig. 15, p. 83.

The doors fit tightly to the side of the furnace, and in most models are opened and closed by hand aided by a counterweight. On late models, Fig. 16, the doors are mechanically operated. The close fit of the doors permits tight luting with fireclay if desired. It will be noted from Figs. 7 and 13 that door construction permits easy removal. The chains are unhooked and the doors lifted out with an overhead crane for relining.

Spare doors already lined are kept on hand thus making the change of these a matter of only a few minutes. The doors are lined with silica brick. They receive severe corrosion, especially noticeable with the front door, and must be changed often.

The Lining.—Nearly all electric furnaces are basic lined,¹ in every case with magnesite brick. Many furnace operators place one course of silica brick or firebrick next to the shell. If these are used they are laid flat with a very thin fireclay mortar, giving a $4\frac{1}{2}$ -in. lining. Following the silica brick, is one course of magnesite brick laid flat with headers exposed.² The lining is now $13\frac{1}{2}$ in. thick and composed of $4\frac{1}{2}$ in. of silica brick and 9 in. of magnesite.

¹ Acid practice is used for castings, very rarely for ingots.

² Headers exposed signifies that the small end section of the brick is exposed. A familiar example is in ordinary brick building construction where every fifth or sixth course has headers exposed.

This method of lining may be varied to suit conditions or the preference of the operator. Although 13½ in. is common for 6-ton furnaces, many are operated successfully with only a 9-in. lining composed of magnesite brick with headers exposed. Other furnaces use a course of firebrick laid flat and parallel to the shell, then a course of magnesite brick laid the same way, and finally the 9 in. of magnesite headers. This makes the lining 18 in. thick. This construction is more often used in the larger hot metal furnaces rather than in the 6 ton.

The brickwork of the bottom is thicker than the walls tapering down to form a circular, cup-shaped cavity. The bottom brick may range from 13 in. in the center of the bottom to 22 in. or more where the cylindrical part of the shell is riveted to the bottom plate, then tapering off again to 13½ in. where it meets the walls. (See Fig. 14, p. 82.)

Magnesite brick are used up to and a little above the slag line. The top course of magnesite is about on a level with the bottom of the side doors. In front, however, it runs up to and surrounds the front door reaching, here, almost to the roof. Above the slag line silica brick are used laid in the same manner as the walls; *i.e.*, one course laid flat and parallel to the shell and one course of headers also laid flat. The silica brick lining extends up to the roof. Some furnacemen use one or two courses of chrome brick to separate the basic from the acid part of the lining. This is, no doubt, an advantage. As a rule, no mortar is used with the magnesite brick nor is any used with the silica brick which are exposed to furnace temperatures; expansion being sufficient to take up all cavities. When the furnace is lined it is ready for burning in the bottom.

Making Bottom.—The final bottom which varies from 13 to 18 in. in thickness may be made in two ways, tamping or burning in. The common method is a combination of the two. The customary material for the bottom is dead-burned ground magnesite. This, mixed with a little ground basic slag and sufficient tar or molasses to make it stick, is shoveled into the furnace and tamped down in layers of 2 or 3 in.¹ After two or three layers are tamped solidly in place, ten to fifteen pieces of broken electrodes some 10 to 12 in. in cross-section are placed in the furnace, the roof put in position, the electrodes lowered and the power turned on. About 16 to 20 hr. is sufficient to sinter the 6 or 8 in. of

¹ The bottom is often rammed in with compressed air rammers.

magnesite to the bottom. The pieces of broken electrodes are now raked out and more of the magnesite and tar mixture shoveled in, being spread in a thin even layer of about 3 in., over the bottom and up onto the walls just above the slag line. The pieces of broken electrodes are again thrown in the furnace, the electrodes lowered and the power turned on. The bottom is then burned in for 20 to 30 hr. longer. As a rule, 48 to 60 hr. burning in is sufficient to sinter the bottom in place permanently. It is now only necessary to make repairs as needed.

A simple and efficient method of making bottom was devised by Clark formerly with the U. S. Steel Corp. and was used by him in installing new furnaces.¹ Three pieces of broken electrodes are chipped on one end into wedged-shaped sections in such a way that they can be fitted closely together in the form of a star. A connecting plug or nipple is chipped so that it will fill the space between the three wedged-shaped sections and the whole cemented together with joint compound. This star-shaped section is placed directly on the magnesite brick. The electrodes are then lowered and the power turned on. The arc playing between the furnace electrodes and the electrode mass on the bottom of the furnace heats the interior to a temperature sufficient to set the bottom. At this point, the bottom material is shoveled in and spread in a thin layer over the brick work. After this is thoroughly fused, a second layer is applied. The whole bottom is thus built up. As often as necessary, the star-shaped electrode contact on the bottom is pried up with bars to make room for additional bottom material.

This method has the advantage that the electrode pieces needed for contact in bottom making do not have to be removed from the furnace at each addition of a layer of bottom material. In addition, this does away with the tamped bottom which, as all furnacemen admit, is not as lasting as the fritted bottom.

Life of Furnace Lining and Bottom.—The life of the lining and bottom varies with the operative conditions and with the skill of the furnaceman. In general, for a furnace operating continuously, that is night and day, $6\frac{1}{2}$ days a week, the lining will last for 75 to 135 heats, or approximately a month's operation under normal conditions. The bottom, with the proper care, should last indefinitely that is, up to 1,000 or 1,500 heats. In fact, there is no

¹ Private communication, John H. Hall, High Bridge N. J., Jan. 9, 1923.

reason why the brickwork in the bottom should not last for years with continuous operation.

The worst corrosion to the lining comes around the slag line and near the doors. The sections near the doors are the hardest to repair while the furnace is in operation, and near the slag line corrosion is always serious.

Relining.—By relining, it does not mean that all of the brickwork needs to be replaced. The furnace is never allowed to get in such bad shape that the first course of brick, that next to the shell is corroded. It is only occasionally, never if the furnaceman is on the job, that slag and metal creep into this section. Relining usually means that the course of silica and magnesite headers is torn out, starting at the roof and working down to a point some 6 or 8 in. below the bottom of the doors. Below this point, the protection afforded by the heavy sintered magnesite bottom is sufficient to keep the brick work here in good condition. The silica brick next to the shell do not, as a rule, need to be replaced. After replacing the worn headers of magnesite brick below the slag line and silica brick above, the furnace is ready to operate.

Relining is nearly always done over the week end. The last heat of the week is tapped about 6 o'clock Saturday evening. The doors are opened wide and the furnace allowed to cool all night. Occasionally compressed air is turned into the furnace to assist in rapid cooling. On Sunday morning, the hot-brick mason¹ starts to tear out the old lining. The new lining is usually in by 9 that night, so the first heat of the week can be made early Monday morning.

Bottom Repairs.—Bottom repairs are made after each heat. The furnace lining and bottom are the hottest just after the heat is tapped making it easiest to sinter the added refractory. When the bottom is in good condition, raw dolomite crushed to pea size is used. This is shoveled in as rapidly as possible immediately after tapping, being added from each side door and thrown far up onto the sides. For spots in the furnace hard to reach by shoveling, a spoon with a bowl some 8 to 10 in. in diameter and a handle about 15 ft. long is used. With this, the refractory can be placed in exactly the right spot.

¹ A hot-brick mason is a bricklayer accustomed to work in very hot furnaces. This branch of bricklaying is a specialty and cannot be done by any mason.

If conditions are not good in the furnace, a better refractory may be used. Double burned dolomite or one of the prepared dolomitic refractories such as magdolite or syndolag may be used or even, in the case of a bad hole, ground magnesite is added. A calcined refractory sinters more rapidly to the bottom than raw dolomite which must have time allowed for the heat of the furnace to drive off the carbon dioxide.

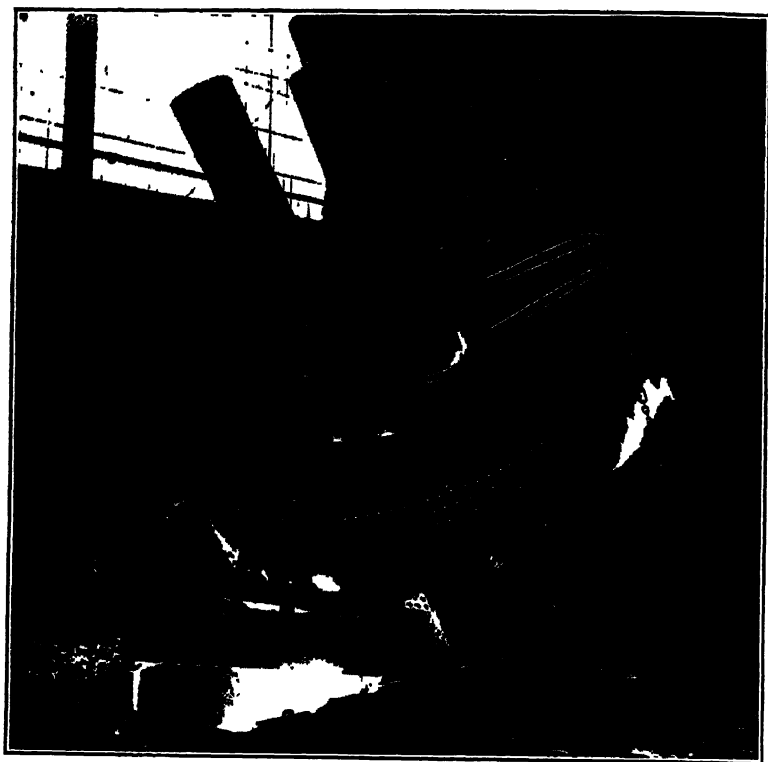


FIG. 13.—Six-ton Heroult furnace tapping, showing roof construction with special shapes.

In regular practice, 150 to 200 lb. of raw dolomite or 75 to 150 lb. of calcined refractory are used after each heat. Repairs between heats take from 10 to 20 min.

The Roof.—In Figs. 13, and 15, p. 83, it will be noted that level with the top of the doors is a ledge. This is the top of the side walls. Above this ledge is the roof. The roof is constructed

of silica brick held by a steel ring, Fig. 13. Two methods of roof construction are used, the construction with special shapes and the construction with regular silica straights.

Figure 13 shows the roof construction with the special shapes. These roof brick are manufactured specially for the furnace and while their cost is a little greater, they are undoubtedly a better form of construction than the regular brick shown in Fig. 32, p. 138.

In building the roof three wooden forms are placed in the position occupied by the electrodes and the brick laid in around these forms. Pieces of thin lumber or laths are used between the brick for expansion joints. When the roof is put in use, these laths burn out, the bricks expanding to take up the cavities. If expansion is not taken into consideration, the roof will buckle and break as soon as heated. To prevent the roof slipping when the furnace is tilted, it is bolted to the shell after being placed in position.

Roofs on a furnace steadily in operation last on an average of 100 heats.¹ It is standard practice to reline the furnace and change the roof at the same time. It is customary to keep one, sometimes two spare roofs made up in case of a sudden failure. When it is necessary to make a rapid change of the roof, the ring is unbolted from the shell, the electrodes are slipped out of their holders and removed completely from the furnace, three chains are hooked to the roof ring in the holes provided, and the whole roof lifted bodily with the crane. Changing the roof takes from 30 min. to 1 hr. It is always desirable, if possible, to change the roof when the furnace is relined.

Tilting the Furnace.—The first installations of Heroult furnaces had hydraulic tilting apparatus. These were soon superseded by motor driven equipment. The motor which is located under the rear of the furnace, in the pit or on the ground if the furnace is elevated, is geared to a rod connected with the back of the furnace. Three methods of tilting have been used. In the first, the furnace sits on a saw tooth rocker, see Fig. 7, p. 59. The motor is geared to a large wheel that actuates the connecting rod and lifts the furnace bodily from the back (see also Fig. 15). The second method of tilting was used on furnaces installed in 1918 to 1920. The tilting mechanism is shown in Fig. 14. The

¹ Longer life than this has been obtained lately from roofs; often 150 heats. The brick are evidently of better grade in the past 2 years

furnace is connected to the concrete piers in front by a shaft whose axis is directly in front and beneath the front door. In the back is suspended a counterweight. This is a large steel box filled with scrap or pig iron. The motor in this case is located just to the rear of the center line of the furnace. This

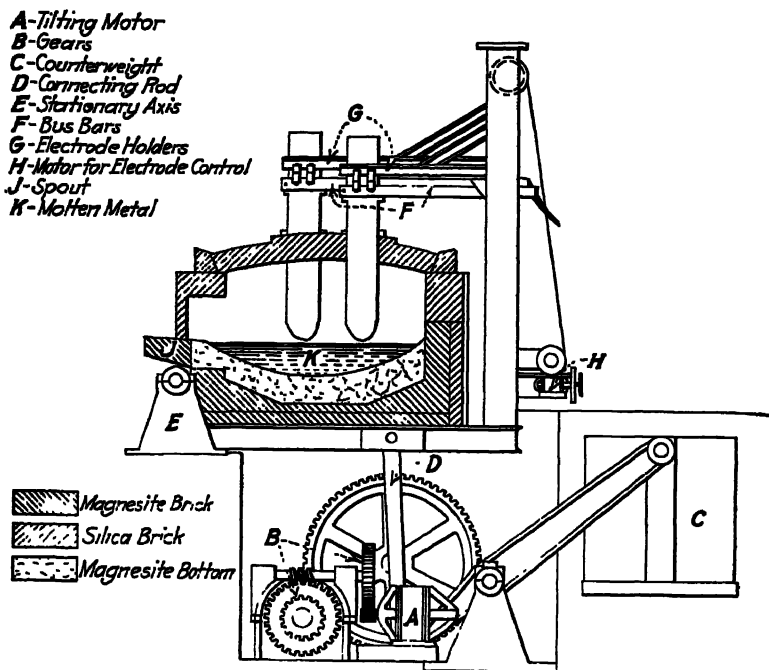


FIG. 14.—Section through a 6-ton Heroult furnace showing tilting mechanism and details of lining.

method of tilting has the advantage that the spout changes position but slightly in tapping.

On the most recent furnaces, the builders have reverted with slight changes to the original tilting mechanism used on furnaces installed about 1916.¹ The details are shown clearly in Figs. 15 and 16. The essential difference in this latest model is the use of rockers of special curvature causing the spout to travel

¹ Furnaces of the pivoted type (Fig. 14) have the disadvantage that it is difficult to clean out any small holes in the front wall just back of the spout, before making bottom repairs between heats. The rocker-type furnaces are easier to maintain at this point.

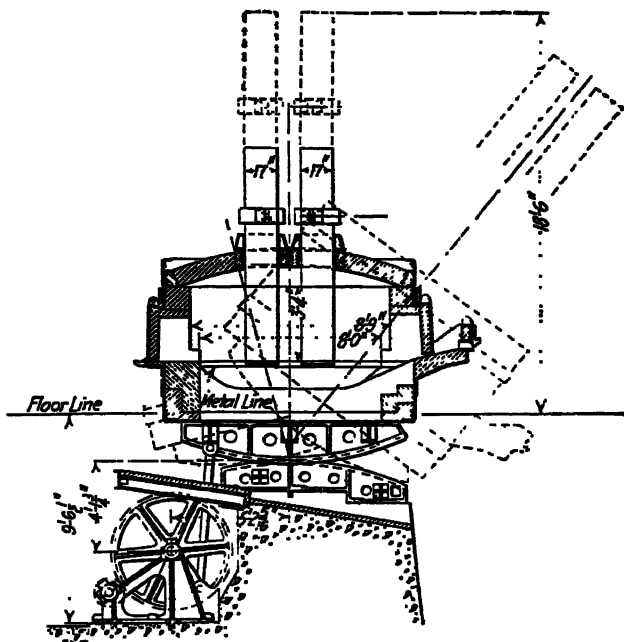


FIG. 15.—Section through a 7-ton Heroult furnace showing tilting mechanism Latest model.

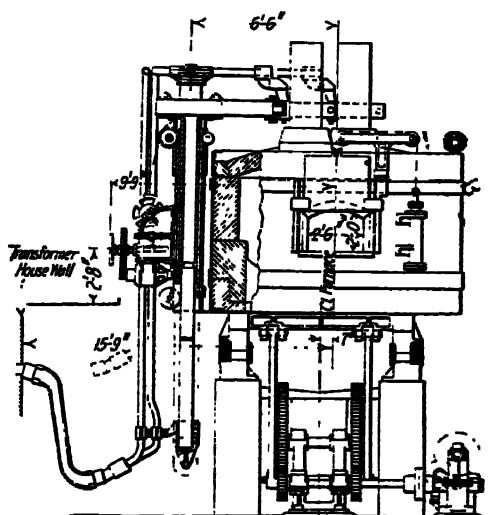


FIG. 16.—Rear view of latest model 7-ton Heroult furnace showing new arrangement of electrode holders.

downward and slightly forward as shown by the dotted lines in Fig. 15.

Tilting is controlled by a controller, operated from a position about 6 ft. in front and 4 to 6 ft. to the side of the furnace. From this position, the operator can control the movement of the stream of metal closely.

Arrangement of Electrode Holders in the New 7-ton Furnace.¹—We have previously described the electrode holders (p. 59) and the method of their control. On the new Heroult

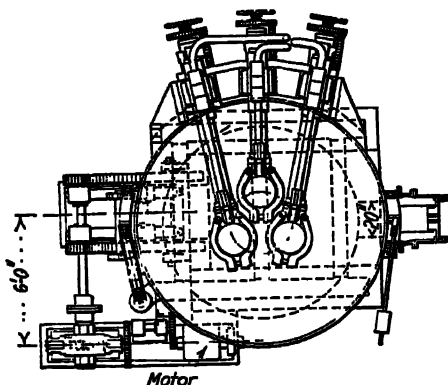


FIG. 17.—Top view of latest model 7-ton Heroult furnace.

just designed, the construction of the electrode mast and the arrangement of the holders has been radically changed.

Figure 16, a back view of the furnace, shows the new arrangement. When the supporting mast is at the side as in Fig. 16, the electrodes may be raised so high by this newly designed control that mechanical charging may be accomplished through the back door without breaking the electrodes. The furnace leads are brought from the transformer underground and connected to the conducting pipes. This, too, is a new departure. Copper pipes are substituted for busbars. The cooling-water passes through the conductor pipes to the electrode holders thence through flexible connections to the electrode cooling rings and then to waste.

The electrodes are attached to stiff cantilever jib cranes whose masts are comparatively short and operate in guides attached to the side of the furnace shell. The electrodes are placed at the

¹ *Iron Age*, vol. 109, p. 235, Feb., 2 1922.

vertices of an equilateral triangle but the triangle is much smaller than in previous furnaces. This is evident by a comparison of Fig. 17 with Fig. 13, p. 80.

THE 30-TON HEROULT FURNACE

The 30-ton Heroult furnace differs but little from the 6-ton described in the previous section except in the electrode control



FIG. 15.—Side view of 30-ton Heroult furnace. Tapping side.

which in the larger sizes is placed on top of the furnace. See Figs. 18 and 19. The electrode control is likewise placed at the side like the newer 7-ton furnaces, instead of at the back as was common 4 or 5 years ago.

The Shell and Doors.—The shell is constructed of steel plates 1 in. thick. It is cylindrical in form and about 16 ft. in diameter. On top of the shell is the roof ring similar to the one

for the 6-ton furnace already described. The bottom of the shell is constructed exactly like the smaller furnace and sets on rockers on which the furnace is tilted.

Figure 19 shows a view of the furnace taken from above, the arrangement and position of the electrode control being clearly

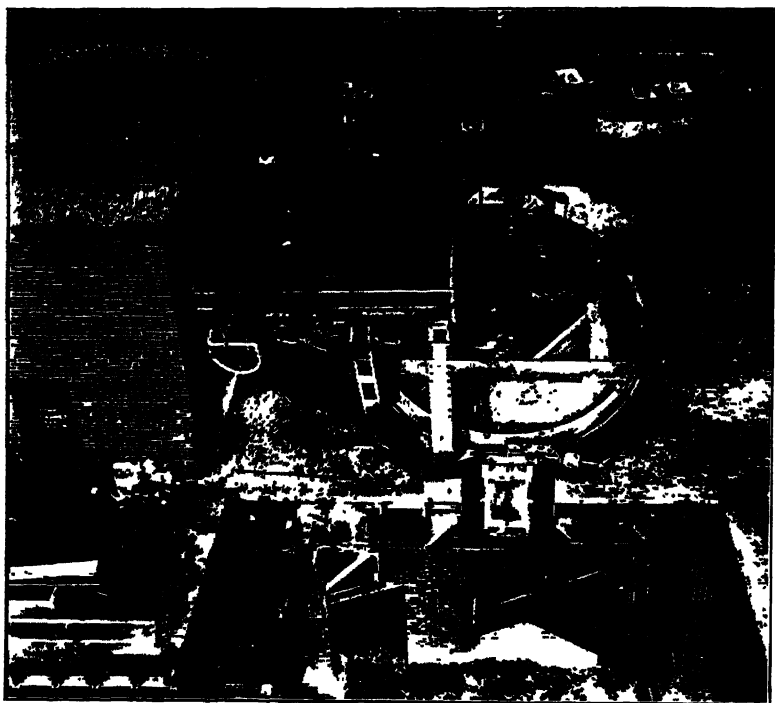


FIG. 19.—Top view of 30-ton Heroult furnace showing roof and arrangement of electrode control.

shown. An individual motor placed on a structural steel framework controls the up and down movement of each electrode by two chains.

In the recent hot metal furnaces, there are three working doors and one tapping door or spout. The electrode control mechanism is at the left of the tapping door Fig. 18. One working door is to the right and one to the left, the other is directly opposite the spout. In furnaces which do not have the control mechanism elevated, there are only two working doors, one behind the

tapping door and one to the right, the electrode control being located on the left.

The door openings are arched in the usual manner. The doors are refractory lined, fit tightly and are controlled hydraulically, occasionally by hand by means of a counterweight.

Electrodes and Electrode Control.—Electrodes have been described at length in a previous chapter. The sizes used for the hot metal furnaces are: Graphite 12- and 14-in. and carbon 24-in. Even after continued experimentation with both kinds of electrodes, it may be said that the superiority of one over the other is still a mooted question. Both have their advantages although, no doubt, graphite are slightly superior for the large hot metal furnaces just as amorphous carbon are somewhat better for the smaller cold scrap furnaces. The electrodes for the larger furnaces are, of course, threaded for continuous feeding and are equipped with nipples of the proper material for joining them together.

The current is supplied to the electrodes by heavy copper cables leading from the transformer house to the furnace where they are welded to individual copper busbars. The control or panel boards with the switches and automatic regulators are similar to those described and illustrated in the previous chapter.

The electrode holder is made of steel and copper, the latter insulated from the steel and serving as the connection between the busbar and the electrode. The two prongs grasping the electrode are held together by screws in identically the same manner as on the 6-ton furnace. The screws may be loosened by a suitable wrench when it is necessary to slip an electrode down. The electrode is cooled at the point where it pierces the roof by a collar or cooling ring (Fig. 19).

The Lining and Roof.—The lining in hot metal furnaces varies in different plants. In general, it consists of one course of silica brick or firebrick next to the shell, and one course of magnesite straights laid endwise (headers). This arrangement is varied by using one course, $4\frac{1}{2}$ in., of silica brick next to the shell, one course, $4\frac{1}{2}$ in., of magnesite and finally the last course of magnesite headers. The former lining is $13\frac{1}{2}$ in. thick; the latter, often used in hot metal furnaces, is 18 in. thick. The bottom is saucer-shaped and is put in as described in a previous chapter, usually by ramming in dead burned magnesite and tar and burning it in for a time sufficient to sinter it into a hard

fused mass. Although the magnesite bottom when tamped may not be thoroughly fused below a depth of 8 in., this method is preferred by most furnacemen to putting in the bottom in thin layers, as a fritted bottom, although conceded to be some better, involves much additional labor for a 30-ton furnace.

The roofs of hot metal furnaces are now mostly made of 12-in. silica brick set on end. A slightly larger brick is used near the roof ring. Furnace men have not taken kindly to the special shapes common in the smaller size furnaces. The 12-in. roof seems to give a maximum amount of life. The corrosion of the silica brick by volatilized fluorine from the slag is considerable, in the 30-ton furnaces at South Charleston, W. Va., the average loss of the roof was about 200 to 300 lb. per heat. For this reason a 9-in. roof is not desirable and a roof thicker than 12 in. would in the larger furnaces be much too heavy. The roof is slightly dome-shaped. (See Figs. 18 and 19.)

Above the slag line, silica bricks are used in the walls and are separated from the magnesite by one or two courses of chrome brick. Linings and roofs in hot metal furnaces working continuously last from 200 to 300 heats, sometimes longer. The wear on both lining and roof is much less, less than half that in a cold scrap furnace.

The bottom should last indefinitely. Repairs to the bottom are made between heats, 200 to 400 lb. of raw dolomite, sometimes dead burned dolomite, are used. The introduction of more satisfactory refractories than those used at present for electric furnace repairs would be very desirable as at least 100, often 200 to 400 lb. of bottom are worn away and carried off by the slag each heat. In addition, the contamination of the slag by such a volume of high magnesia refractory makes it necessary to use a very pure lime for slag-making in order to maintain the proper amount of calcium oxide in the slag.

CHAPTER V

OTHER DIRECT ARC FURNACES

General Features of the Conducting Hearth Furnace—The Greaves-Etchells Furnace—The Moore "Rapid 'Lectromelt'" Furnace—Other Direct Arc Furnaces—Recent Foreign Furnaces

In a foregoing chapter we discussed arc furnaces in general and noted that the most practical from the American steel maker's viewpoint were those of the direct arc type with or without a conducting hearth. These furnaces are the most practical and successful because their operating practice conforms closest to the ideas of the American electric steel maker; namely, quality, tonnage and cost. The American melter greatly dislikes to "play" with his heat, he wants to get it out of the furnace as quickly as is consistent with good practice. This characteristic has resulted in the development of four or five successful furnaces; furnaces constructed to facilitate this rapid operation. In addition it has relegated several furnaces used commonly a few years ago to almost complete oblivion.

In Chap. IV we described in some detail the Heroult furnace, because it is the most popular furnace and the one leading in installations and because it is the best representative of the direct arc furnace with a non-conducting hearth. This type has some noteworthy disadvantages especially violent current surges during melting and little or no movement of the molten metal through convection currents. As furnaces of the Heroult type are series arc, breaking the arc of one electrode will break all three and will lead to heavy power surges. This, of course, only holds for melting cold scrap as there is little possibility of an arc breaking in a hot metal furnace. In regard to convection currents the advantage of a movable metal is, in most cases, unquestioned.

In view of the disadvantages noted above, particularly the disadvantage of violent power surges in a series arc furnace, we will take up in the present chapter the general features of the direct arc furnace having a conducting hearth, principally because this type has been heralded as the nearest approach to mechanical and electrical perfection for steel making.

GENERAL FEATURES OF THE CONDUCTING HEARTH FURNACE

Owing to the above-mentioned metallurgical and electrical disadvantages of the three-top-electrode furnace as typified by the Heroult, attempts were made in the infancy of electric melting to secure some bottom heat and also some method of checking the violent current surges that are bound to occur in all series arc furnaces. The result was furnaces of the Girod type in which the current after being led in through one to four top electrodes had to pass through the charge and out at four, six or eight water-cooled steel studs that were inserted through the furnace hearth, the upper ends of which were in direct contact with the molten metal. No power was put through these studs; they simply received power or out-of-balance loads, this power being led to the center point of the Y connection.

This design resulted in an immediate improvement in the steadiness of the load and power factor and in addition resulted in a slight amount of circulation of the metal. These convection currents were seen at once to be a valuable aid in refining and equalizing the temperature at all points of the bath. The practical difficulties of water cooling and the troubles of keeping the hearth in good condition with these steel projections through it resulted in the almost complete abandonment of this type furnace in America.

Different Classes of Bottom Electrode Furnaces.—In an effort to overcome some of the disadvantages of water cooled steel bottom electrodes, furnace builders resorted to other types of bottom contact. One of these is the Grönwall or Electro Metals, an English built furnace. (Described on p. 108.) Instead of steel studs in the hearth this furnace has a thin highly conductive hearth with copper projections well up into the lining. With careful handling this furnace operates better than the direct arc, non-conducting hearth or Heroult type but has not become widely adopted, in this country at least, because of the thin lining.

The Moore furnace (p. 97) has a very thin copper conductor on the furnace hearth and connected to the neutral point in the system. This would only operate when the furnace load was out of balance and is consequently of no use as a source of heat or power.

In these types, whether the bottom contact is a copper plate or water-cooled steel studs they have the disadvantage that no

power is received through the bottom contact; it simply receives power introduced through the top electrodes and although it serves to eliminate to a degree some of the surges present with the Heroult type it does not, to any extent, make resistance heating a noticeable factor in the operation of the furnace.

Resistive Hearth Furnaces.—The disadvantage of the non-conducting hearth, namely, violent current surges, and the disadvantages of the bottom electrode furnace, bottom trouble and absence of resistance heating, are partly overcome in furnaces of the Greaves-Etchells type. This furnace will be described in detail in the next section. The essential feature of this type is the use of three phase current with two or multiples of two top electrodes attached to two phases of the power supply and the third phase to the whole of the furnace hearth. There are no steel nor carbon studs projecting into the refractories—it is just a plain refractory lining from 18 to 36 in. thick purposely made resistive where it comes into contact with the charge.

Current distribution is so arranged that the whole of the hearth acts as one electrode and power can be forced through any thickness of lining. The current transmitted by the hearth of the furnace can be varied from zero to a definite ratio of the sum of the currents through all of the electrodes. The electrical connections are such that all of the power may be introduced through the top electrodes or by changing the position of an oil switch through top electrodes and the furnace hearth. A balanced load and independent control of each electrode is obtained with either system.

In starting up a cold furnace power may be introduced through the top electrodes only or if the bottom connection is wanted, through top and bottom. In the latter case the current first arcs over the charge then passes through the whole charge, small arcs being formed wherever there is poor contact in the scrap and finally, the resistance of the hearth generates heat right under the charge.

Convection Currents.—One of the greatest advantages of the conducting hearth furnace is the movement of the metal bath caused by convection currents. Due to the resistance of the bottom refractories considerable heat is generated, which is, of course, imparted to the metal in the immediate vicinity. The metal being hotter here, rises and there is thus a constant circulation of the bath from bottom to top and from top to bottom.

This circulation prevents any possibility of localized overheating in any part of the bath and insures that the metal is uniformly heated throughout its whole mass. This is especially valuable in alloy steel manufacture, as many of the heavier alloys tend to settle to the bottom of the furnace. To promote uniformity of composition and constancy of temperature in the Heroult, for example, the bath must be frequently stirred. This is a job that the furnaceman dreads and always avoids if possible. It is claimed that through these convection currents, the bath is constantly mixed and thus stirring or "shaking up" is not necessary.

These convection currents aid greatly in refining as the metal in contact with the slag is constantly changing. In the early part of the deoxidizing period this is a great advantage as slag reactions are speeded up and deoxidation is thus facilitated. There are many furnacemen who argue against convection currents as defeating in part the quiet dead-melted condition desirable for an elimination of the solid non-metallic reaction products. This is debatable and will be taken up again in the chapter on the chemistry of the process. It is undoubtedly true though, that the movement occasioned by convection currents is so gentle that this condition may be considered analogous to a quiet dead-melted bath.

THE GREAVES-ETCHELLS FURNACE¹

In the previous section we have, under the topic resistive hearth furnaces, taken up the electrical details of the Greaves-Etchells as typical of this class of furnace. It only remains to describe the construction details of the furnace and emphasize the points wherein it differs from other well known furnaces of the direct arc class.

General Construction Features.—The Greaves-Etchells furnace shown in Fig. 20 is constructed in sizes ranging from 500 lb. to 60 tons. The most common sizes are the 3, 6 and 10 tons. It is a comparatively modern furnace, being introduced in England in 1915. More than 60 furnaces are in operation, 28 of them in America. Even though the furnace is less than 10

¹ The author is indebted to Frank Hodson, President of the Electric Furnace Construction Co., Philadelphia, Pa., for most of the data on the Greaves-Etchells furnace.

years old it ranks second in point of tonnage, being exceeded by the Heroult only.

The furnace operates on either two or three phase current, any voltage or frequency. Like all other furnaces the three phase is the standard construction. Two of the phases are connected to the electrodes, the other with the bottom of the hearth (Fig. 21). Three phase small furnaces have two electrodes, large ones multiples of two.



FIG. 20.—Three-ton Greaves-Etchells furnace

Electrode control is automatic and is commonly by the make-and-break contact regulators of the General Electric Co. described in a previous chapter. Westinghouse regulators may also be used.

The furnace shell is either round or square in plan, nearly always round in the smaller sizes and may be lined either acid or basic. The latter is used in most cases.

The furnace is mounted on rockers and is balanced so that only a small amount of power is necessary to tilt. This is furnished by an electric motor situated apart from the furnace. The tilting mechanism is arranged so that should anything happen to it the furnace will return to its normal position.

The Lining.—Most Greaves-Etchells furnaces are basic lined. The refractory hearth, while non-conducting when cold becomes a conductor at furnace temperatures. Figure 21 shows details of the electrical connection with the hearth. *H* is a copper plate laid directly on the shell. On this plate is a layer of graphite which is mixed with tar and is rammed into place. On top of the graphite is a second conductive layer of 4 in. of amor-

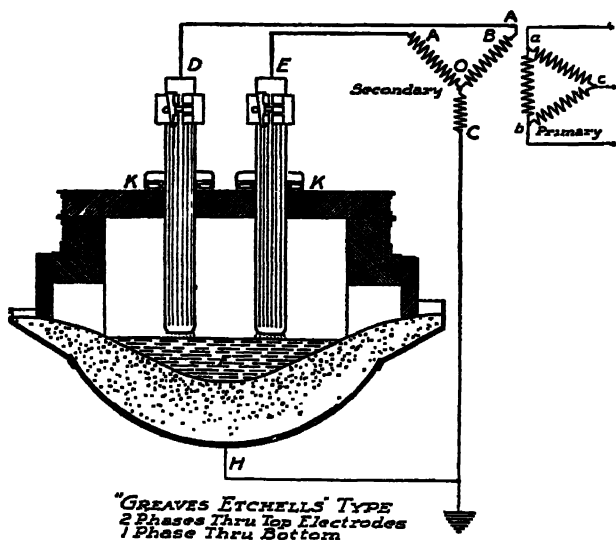


FIG. 21.—Section through a Greaves-Etchells furnace showing electric hearth connection.

phous carbon. When these two layers are in place the regular refractory bottom is put in. This is composed of magnesite or a mixture of magnesite and dolomite and hot tar. It is shoveled into the furnace and rammed or tamped solidly into place.

It will be at once noted that in the Greaves-Etchells furnace no brick are used in the bottom. This is in direct contrast with accepted methods of bottom-making as practiced in the Heroult. The makers of the furnace claim that it is remarkably free from bottom trouble and attribute this freedom to the fact that the bottom is at all times very hot which makes it impossible for steel to be left in the furnace when tapping, this steel to chill on the bottom and be later melted and worked down into the lining when melting down the next heat.

After the bottom is rammed in a bed of coke is placed on the hearth and the current turned on the furnace. Due to the conductivity of the hearth the refractories are sintered into place very thoroughly. In starting the baking there is enough carbonaceous material in the form of tar to complete the circuit. As

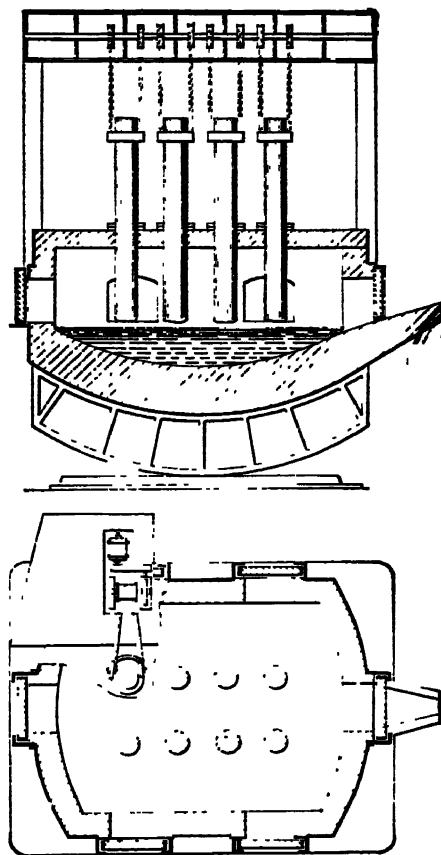


FIG. 22.—Section through 60 80-ton Greaves-Etchells furnace.

this distills out the hearth gets progressively hotter until the refractories have become conducting by the time the binder is completely expelled.

The Greaves-Etchells Hot Metal Furnace.—An interesting development in hot metal electric furnaces is the 60 80-ton Greaves-Etchells furnace now being constructed for the Ford Motor Co. The diagrammatic plan and elevation are shown

in Fig. 22. The furnace will be equipped with eight 12 in. graphite electrodes and with transformers of 12,000 kva. capacity. The electrodes are arranged in two rows of four. Each row of four together with the hearth forms an electrical unit and is supplied by a 3,000 kva., three phase transformer. By means of a switch the power can, if desired, be put entirely through the top electrodes thus greater flexibility is obtained as the top operation can be used in starting up the heat and by changing the oil switch heat can then be applied through the hearth for getting the circulation of the bath necessary for quick refining.

The furnace is designed like an open hearth, has five doors and tilts endwise. The electrode motors and winches are mounted on a framework on top of the furnace. Each electrode holder is lifted by two chains which pass over the sheaves and then directly to the winding drum.¹ The bus bars from each transformer pass interlaced to a point from which flexible copper strips lead to electrode holders. Each holder is provided with insulated guides passing through the superstructure. Each electrode is fitted with the Electric Furnace Construction Co.'s electrode economizer described on p. 70.

Operating Features of the Greaves-Etchells Furnace.—The most important feature of the Greaves-Etchells, an advantage not present in the Heroult, is the resistive hearth. This construction feature performs two functions: (1) It eliminates current surges and (2) it causes convection currents.

In addition the electrical hook-up prevents that undesirable condition present in a series arc furnace of the Heroult type; a condition whereby all three arcs are broken if the arc on any one electrode breaks. The independent electrode control of the Greaves-Etchells whereby each electrode arcs separately entirely prevents this undesirable condition from ever occurring.

The makers of the Greaves-Etchells furnace guarantee that the power factor will be at least eight per cent better than the Heroult. This means that the figure must be between .94 and .96 as the Heroult in ordinary practice will average from .88 to .90. This higher power factor together with the absence of violent current surges should make the Greaves-Etchells very attractive to the central station company.

¹ This is practically the same arrangement of electrode control used on the 30-ton Heroult at the U. S. Naval Ordnance Plant and illustrated in Fig. 19, p. 86.

The electrode arrangement of the Greaves-Etchells whereby the furnace may have any number of multiples of two electrodes is a great advantage in the construction of the large hot metal furnaces. In furnaces of the Heroult type having three electrodes in series it is probable that the present 30/40-ton furnace described in the previous chapter is about as large as can be constructed without a radical change in design. Already the bath is so large and the banks so far from the electrodes that it is very difficult to melt a bank skull. Likewise a uniform temperature and a homogeneous metal are difficult to attain. In the Greaves-Etchells this condition is not present. However, increasing the number of electrodes also increases the number of holes in the roof and thus produces a source of weakness already serious even in three-electrode furnaces. Although this will not be known definitely until the 60-ton Greaves-Etchells is in operation it is probable that the life of the roof will be short. Opposed to this assumption the maker claims that because of the bottom tap localized overheating of the roof is impossible. This may offset, in part at least, the weakness caused by eight electrodes.

In this connection a published statement giving the length of life of the roof, lining and bottom of the new 60 80-ton Greaves-Etchells furnace at the Ford Motor Co. will be of great value to all electric furnace operators interested in the production of electric steel in large units.

THE MOORE "RAPID 'LECTROMELT" FURNACE

The Moore Rapid 'Lectromelt furnace is one of the latest and most successful developments of the small direct arc furnace. Its advance has been rapid, more than 50 installations being made to date. It is apparently very successful in the manufacture of iron and steel castings although it is well adapted to ingot production. Most of the furnaces are 3 tons or less as this size is best suited for the production of castings in the small foundry. The furnace is rugged, strong and simple in construction. It is fast melting and economical to operate as well.

General Construction Features.—A view of the Moore Rapid 'Lectromelt furnace is shown in Fig. 23. It is a circular steel shell, heavily reinforced and lined with refractory materials.

The lining and process may be either acid or basic. The furnace has been used mostly for the manufacture of castings by the acid process.

The Moore uses three phase current at 25 or 60 cycles, introduced into the furnace by three carbon or graphite electrodes set at the vertices of a small isosceles triangle (Fig. 24). The electrode holders are also the current conductors and move vertically on stiff tubular masts operated by motors located apart



FIG. 23.—Three-ton Moore "Rapid Electromelt" furnace.

from the furnace. The electrode arms may be raised and swung clear of the furnace. Roofs may thus be changed without unshipping the electrodes. This is an advantage over the Heroult as with the latter the electrodes must be removed completely from the holders before the roof can be changed. This advantage, though, is of small moment as roof changes are nearly always made on Sunday. Electrode control on the Moore furnace is automatic; the standard make-and-break regulating contactors are used. Hand control is also provided for each electrode.

The furnace tilts by hand, by a wheel located to the right of the spout (Fig. 23). The tilting mechanism is of special

design and is fitted with ball bearings making hand tilting a comparatively simple operation. A motor may be used for tilting if desired. In either case the tilting mechanism is so constructed that all apparatus is at floor level where the danger of slag or metal splashing on motors or gears is minimized. The furnace tilts forward and backward, forward for tapping and backward for slagging. The doors, two in number, fit tightly to the shell and are operated by hand by means of counterweights.

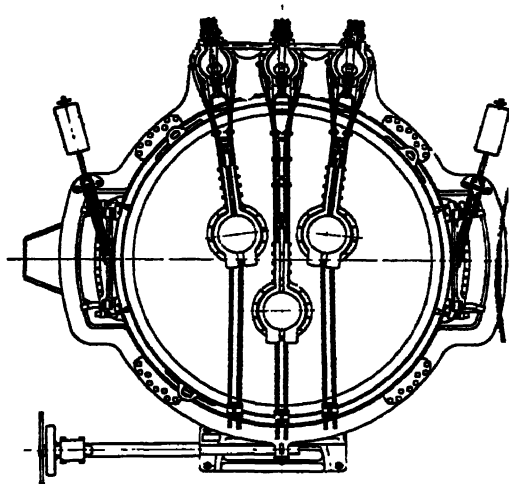


FIG. 24 -- Plan of the Moore furnace

Operating Features of the Moore Furnace. -The Moore is not properly a conducting hearth furnace, that is, conducting in the sense that the Greaves-Etchells is. The hearth contains a copper conductor which forms the neutral connection and takes up any out-of-balance load. The furnace has a power factor averaging between .85 and .90, which is about as good as the average. Examination of load curves shows the furnace to be quite free from violent current surges that happen frequently with the series arc connection and the non-conducting hearth. It is probable that the Moore is slightly more efficient electrically than furnaces of the Heroult type.

No records are available concerning the performance of the Moore on hot metal nor on the regular run of alloy and tool steels that makes up the usual product of the 6-ton Heroult. On

castings the Moore requires 458 kw.-hr. per ton of metal poured and 640 kw.-hr. per ton of castings shipped. It is probable that on the average alloy steel the current consumption would be about 750 kw.-hr. which is practically the same as the Heroult.

The hearth of the Moore is unusually shallow. This coupled with its larger area increases the capacity. It is customary for the furnace to be overcharged at least 50 per cent, often 100 per cent. The 3-ton furnace will charge 9,000 to 10,000 lb. regularly. It is claimed that the hearth design has the additional advantage of decreasing radiation thus increasing the life of the refractories. The maker advises that the average roof will last 300 to 350 heats and cites one instance of 672 heats. This, of course, is for acid practice where little if any refining is accomplished and where the elapsed time of a heat rarely exceeds 2 or 3 hr. The roof life would be much shorter if the furnace was operated regularly on alloy and tool steels made on a basic bottom and requiring about 3 hr. deoxidation.

There is no doubt that the Moore is a very fast and efficient melting furnace. It has acquired an excellent reputation in the foundry and produces superior castings of both iron and steel. It is but little different from the Heroult in general construction. The few improvements are mostly mechanical and electrical. The electrode arrangement is good, possibly no better than the latest Heroult. The fact that it has eclipsed all other furnaces in recent new installations is sufficient proof of its efficiency; although until it has operated over a period of time on carbon, simple alloy and high speed steel ingots we would not attempt to say definitely that it is superior to the Heroult.

OTHER DIRECT ARC FURNACES

There are five other direct arc furnaces that deserve brief mention.¹ Three of them, the Ludlum, Vom Baur and Volta are tonnage furnaces, their most common capacity is 6 to 10 tons. The Greene Rolling Cylinder Arc Furnace, a small furnace of

¹ A furnace formerly successful but now discontinued is the Snyder. This piece of equipment as originally built was later modified into a Heroult type furnace and called the Industrial. The Snyder patents are now held by the Repel-Arc Furnace Co., who build a small direct arc furnace for melting non-ferrous alloys. Another furnace used but little is the Booth. This furnace was originally a direct arc, conducting hearth furnace but was later changed to the Heroult type.

unusual design, is built on the Pacific coast and has met with considerable success in Western foundries. All of the above mentioned furnaces, while having but few installations, are successfully operating in this country and Canada. One other furnace, the Girod, used successfully abroad but discontinued in this country is taken up here because it was one of the first bottom-electrode furnaces. A description of the Girod will conveniently include the reasons why this furnace has not been favored by American furnacemen.

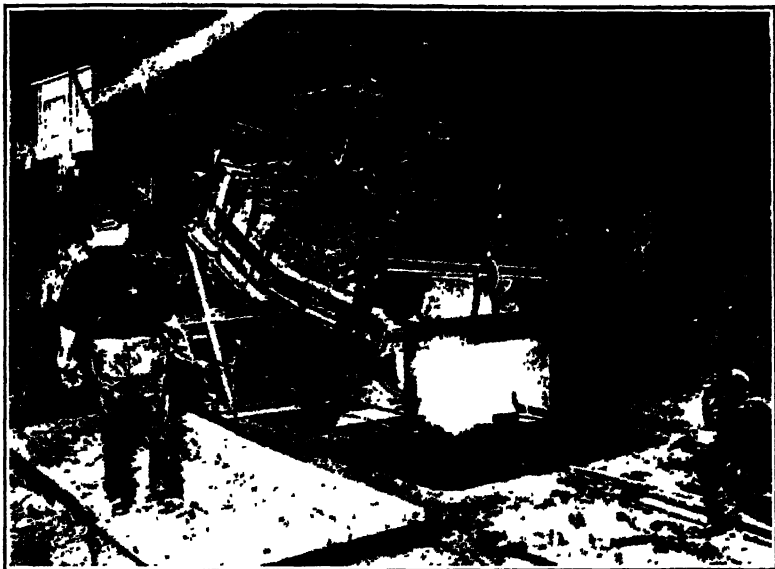


FIG. 25.—Ten-ton Ludlum furnace.

The Ludlum Furnace.—The Ludlum furnace is a three phase, three electrode, direct arc furnace with a non-conducting hearth. It is elliptical in plan with the electrodes spaced in a row instead of the familiar triangular arrangement used by the Heroult. This is clearly shown in Fig. 25. The hearth has less depth than commonly employed in a Heroult of same capacity, thus increasing the area of contact between metal and slag. The builder claims that refining is thus facilitated, and that a circulation of the metal results without the use of a conducting hearth.

This electrode arrangement together with the elliptical hearth permits the supplying of current at the highest rate during

rior to the latter through minor electrical and mechanical improvements.

In brief, it may be said that the Volta is a Heroult furnace constructed in the same way, but with minor improvements. There are no radical differences in the method of operating. The long experience of furnacemen with the Heroult is an advantage that applies to the Volta in every respect. There are eleven furnaces operating in Canada and two in the United States.

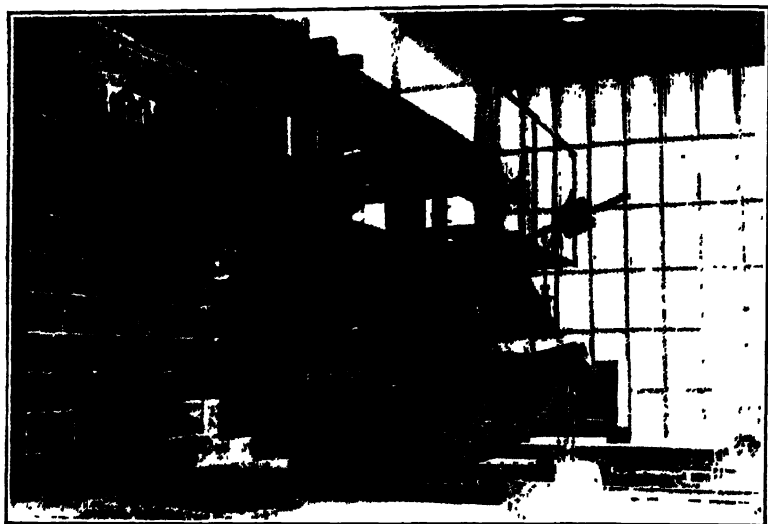


FIG. 27.—Green Rolling Cylinder arc furnace.

The Greene Electric Furnace.—The Greene Rolling Cylinder furnace differs more radically from the Heroult than any of the direct arc furnaces (see Fig. 27). The shell is a cylinder with outwardly bulging ends one of which contains the working door. The tapping door is in the center of the front cylindrical surface with the electrode mast directly opposite. One, two, three or more electrodes are placed in a row (Fig. 27). The furnace has a non-conducting hearth.

Aside from the shape of the shell and arrangement of the doors and electrodes the Greene differs from other arc furnaces in the way it is lined. The bottom is unusually thick for the capacity, being about 24 in.; the walls are two courses, one of insulating and one of refractory brick. The roof is arched and may be removed

altogether to permit charging or repairs. Electrode regulation is by hand although automatic regulators may easily be installed. The cables carrying the current run directly to the electrode holders; thus no busbars are used.

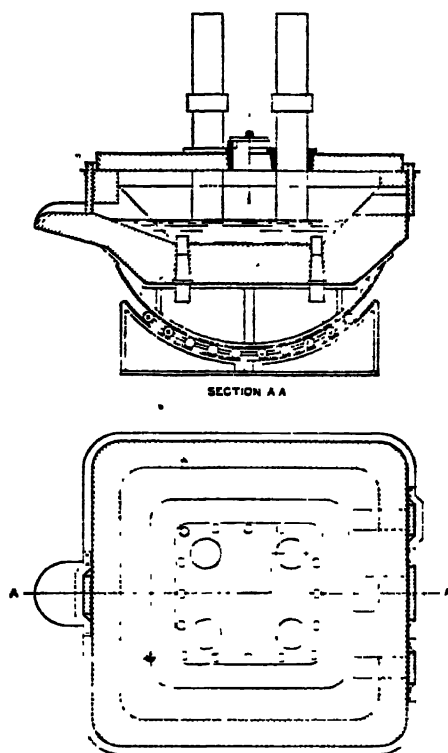


FIG. 28.—Sectional view of 10-ton Girod furnace.

The furnace is tilted by hand or hydraulic cylinders. The shell rolls over on the rails which form the base; the spout travels down and but slightly forward. This makes it convenient in pouring into hand ladles. The Greene furnace is built in sizes up to 3 tons, the common capacity being 500, 1,500 and 3,000 lb. Most of the installations are acid-lined and are used for castings.

The Girod Furnace.—The Girod is the earliest example of the direct arc, conducting hearth type with a bottom electrode. It is a tilting furnace generally square in plan and uses either single or three phase current. A section view is shown in Fig. 28.

The single phase has one top electrode; the three phase four. Single phase furnaces are no longer important either with the Girod or any other type. In the Girod three phase arrangement, each of two electrodes is connected to a phase, the other two are connected in parallel with the third phase and the hearth connected to form the neutral point of the system.

The bottom tap is composed of a number (usually 16) of soft steel bars embedded in the refractory hearth, each of them being water cooled at the bottom. The upper part of the bottom electrodes becomes melted off but is supposedly¹ renewed again by frozen metal collected on them at the end of the heat. This does not always work out well in practice. The electrodes melt off, the molten metal works down and creeps into the magnesite hearth undermining it and causing many difficulties in keeping it in good condition.

An advantage held by the Girod is the steady load on cold scrap due to the even flow of the current from and to the bottom electrode, thus heating by resistance as well as by the arc. Whether this advantage of even load is sufficient to overcome the disadvantages of possible bottom trouble is questionable. Probably the disadvantages of the bottom electrode are of greater moment—they surely are to the American steel maker—than the advantages of elimination of current surges.

There are few Girod installations of importance in this country although the furnace has been operated successfully abroad for a number of years.

RECENT FOREIGN FURNACES

Four furnaces operated successfully in Great Britain, France, Germany and Italy, but not used to any extent in America are worthy of brief mention. The newest of these furnaces is the Fiat, an Italian piece of apparatus. The others are the Electro-Metals and Stobie in England and the Nathusius in Germany. The Fiat is the most important, chiefly because of the electrode economizer used, and will be discussed in some detail; the others will receive but brief mention.

The Fiat Electric Furnace.¹—The Fiat furnace was introduced in 1916. The furnace consists of a cylindrical steel shell having a saucer-shaped bottom and lined with refractory materials. The

¹ Abstracted from *Chem. Met. Eng.*, vol. 27, No. 1, pp. 28-30.

shell is pierced by two doors, one for charging and slagging, the other directly opposite for tapping. The furnace is a direct arc type with a non-conducting hearth, and operates on three phase current at about 100 volts. The electrodes are held in position by a special structural steel framework attached, but independent of the furnace proper. By means of a crane the electrode holders, electrodes and steel framework, in fact all of the superstructure, can be removed completely and quickly from the furnace.

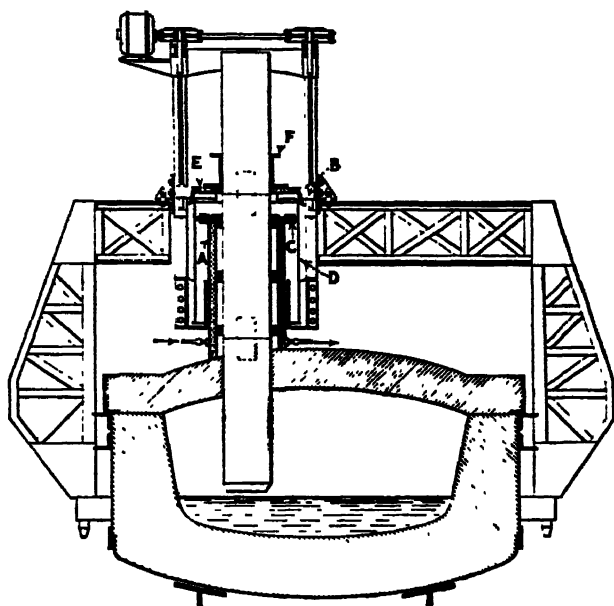


FIG. 29.—Sectional view through Fiat furnace and special economizer

The most important feature of the Fiat furnace is the special economizer shown in Fig. 29. This economizer is composed of a cylindrical water jacket, *A*, through which the electrode passes. A series of insulating guide rings are contained in this cylinder and serve as guides for the electrode in its up-and-down movement and prevents the electrode from touching the walls of this metallic cylinder. *C* is a circular layer of asbestos acting as a packing ring and in which moves a sealing bell, a cylinder of copper attached to a steel disk, *B*, which forms the cover. The electrode passes through a hole in this cover. On the cover is located an insulating disc, *E*, and on this is fastened the bronze

clamp, *F*, which grips the electrode. The electrode and clamp are thus connected tightly with the bell making the electrode hermetically sealed preventing the circulation of air through the furnace.

As a result of this seal, oxidation of the electrode is prevented and electrode consumption greatly reduced. The actual consumption was found to be 2.85 kg. (6.3 lb.) per ton for 21 heats of 5 tons each. The perfect seal prevents the circulation of air in the furnace and thus the atmosphere above the bath is kept constantly neutral.¹ The cross-section of the electrodes remains constant, no penciling ever occurs. It is therefore possible to speed up the furnace by introducing more current into the bath by means of increased electrode size, greater transformer capacity, and larger cables.

It is stated that a heat may be made in 3 hr., tap to tap, with hand charging and with a current consumption of 640 kw.-hr. per ton. It was also stated that nine heats were made in exactly 24 hr.; the charge in each case consisted on 4,675 kg. (10,265 lb.) of scrap without additions. This speed is quite remarkable and if attained consistently proves the Fiat to be one of the fastest melting furnaces yet developed. The tonnage produced, 46 tons in 24 hr. is nearly double the average of the 6-ton Heroult which over a long period (5 years) averaged 25 tons of ingots per 24-hr. day. The article from which this abstract is taken does not state whether the furnace was acid or basic lined but from the statement that $1\frac{1}{2}$ hr., were necessary to melt and $1\frac{1}{2}$ hr. to refine it seems probable that acid steel was made. If this is the case, 3 hr. is not especially remarkable, because in acid casting work it is only a matter of melting down and tapping, little if any refining being accomplished.

The design of the furnace proper shows no remarkable features or improvements over the best American furnaces. The electrode economizer is unique in its construction and is a valuable addition to a direct arc furnace.

Since 1917, six 6-ton furnaces and one $1\frac{1}{2}$ -ton furnace have been constructed and installed.

The Electro-Metals Furnace.—The Electro-Metals steel furnace is a direct arc furnace with a conducting hearth. It is a development of the Grönwall and consists essentially of a steel

¹ If the seal is perfect, the atmosphere is more apt to be reducing due to volatilized carbon (Author).

shell having a thin refractory hearth in which are embedded a number of copper studs. It uses either two or three phase current. Furnaces of 5 tons or less have two electrodes, furnaces of more than 5 tons four.

It is claimed for the Electro-Metals furnace that the load is steady when cold scrap is melted, as the arcs are not connected in series; each may be regulated separately. Electro-Metals Ltd., the makers of the furnace, have also developed an electrode economizer which has reduced electrode consumption from 15 to 11 lb. per ton. The furnaces are built up to 30 tons capacity and most of them are installed in England. The bottom electrodes, because they are not directly in contact with the metal, do not cause trouble with the hearth as is the case when the construction is similar to the Girod. From the available information the Electro-Metals furnace resembles closely the Greaves-Etchells, in the details of handling the current, at least.

The Stobie Furnace.—The Stobie is a recent direct arc furnace with a non-conducting hearth. It is octagonal in plan, has four electrodes and uses two phase current. It is built in sizes up to 15 tons. The Stobie follows the Heroult furnace closely in construction, especially in electrical details. Patent electrode economizers are supplied with the furnace that afford a perfect seal and thus reduce electrode consumption and power losses. It is claimed that electrode consumption averages $6\frac{1}{2}$ lb. per ton; this record being made for an operating period of 6 months.

The electrode-carrying superstructure is not the usual gallows arm type but is composed of a rigid bridge secured on all sides of the furnace. The furnace is mounted on roller bearings and is tilted by a motor. Power consumption is about 625 kw.-hr. per ton. The power factor ranges from .85 to .93. The Stobie is an English built and operated furnace.

The Nathusius Furnace.—The Nathusius is a German made furnace. It is three phase, three electrode with a conducting hearth. The hearth conductor consists of three bottom water cooled mild steel electrodes set in the refractories. Both upper and lower electrodes are arranged in a triangle.

The upper electrodes are suspended by cables from overhead runways and are regulated either automatically or by hand. The voltage between the upper electrodes is 110, between the bottom electrodes 10, and between upper and lower about 60. The furnace sets on trunions and is tilted by a motor. The electrodes

are raised clear of the furnace when tapping. The Nathusius is very similar in construction to the Girod but it is claimed that it does not have the bottom trouble sometimes present with the latter furnace.

Summary.—We may now summarize the characteristics of the various types of arc furnaces. We have seen from the description of the arc furnaces in the foregoing that two general types are successful in American practice; the direct arc with a non-conducting hearth, including the Heroult, Moore,¹ Ludlum, Vom Baur, Volta and Greene; and the direct arc, the hearth of which is a separate conductor, including the Greaves-Etchells. We have also seen that the bottom electrode furnace, as typified by the Girod, is not successful in this country.

The chief point in favor of the direct arc with the non-conducting hearth as typified by the Heroult, is that it is one of the oldest and best known class of furnaces, consequently it is well standardized and developed. More furnacemen are familiar with it than with any other type. The years of experience with the Heroult and kindred furnaces has served to make them very efficient steel-making mediums. They are well adapted to cold scrap although having more-or-less violent power surges during the melting period. They are particularly efficient in refining molten metal charges. They are probably as near "fool-proof" as any electric furnace and do not demand any unusual care or knowledge in maintenance and repairs. Their power factor is high, and except for the erratic current consumption in the first part of the melting period, they are attractive to the central station. They will produce, if intelligently operated, steel of the highest quality in sizable tonnages and do it with regularity. A possible disadvantage when the arcs are connected in series, as is the case with most of them, is the breaking of all arcs if one electrode fails to make contact. This may be, and is now, largely prevented by intelligent charging.

Most of the possible disadvantages present in the non-conducting hearth furnace are eliminated by the conducting hearth. The problem of elimination of violent current surges is not, however, wholly solved even here as the hearth does not become conducting until heated. This means that for a short time at least, when starting with a cold furnace, there is a possibility of

¹ The Moore has a conductor laid on the shell connected to the neutral point of the system.

current surges when power is first put on. The arrangement by which each electrode acts independently of the other two distributes the load more evenly, than if the arcs are connected in series.

Convection currents are without doubt a valuable aid in refining and equalizing the temperature in the bath, thus preventing any overheating of the metal and refractories and aiding in the rapid distribution and thorough mixing of added alloys. Whether a movement of the bath aids in eliminating solid non-metallic inclusions and gases is a disputed question.

Furnaces with bottom electrodes, water cooled or not, seem prone to bottom trouble. These furnaces have, however, a very even load and are more nearly free from current surges than any other existing type. It is probable that bottom electrode furnaces would give satisfaction if properly constructed and intelligently operated.

We may, from the foregoing, conclude that:

(1) Direct arc furnaces having a non-conducting hearth have the disadvantages of power fluctuations in melting, and no convection currents to aid refining, but have the great advantages of popularity; excellent development both mechanically and electrically; perfect adaptability to any class of work—cold scrap, hot metal, iron, or steel; and most important, a well standardized operating practice covering a number of years of experience.

(2) Direct arc furnaces having a hearth that becomes conducting at high temperatures have the advantages of even load without the violent surges common to the other type and have convection currents or a movement of the metal that aids in refining and equalizing the temperature. Their principal disadvantage is their lack of popularity and the lack of experience steel makers have had with the type. They have not, with the possible exception of the Greaves-Etchells, been used extensively to refine molten charges but work very efficiently with cold scrap.

(3) The direct arc conducting hearth furnaces with a bottom electrode have the advantage of even load with cold scrap and consequent absence of current surges. In this respect they rank higher than any other type of direct arc furnace. Their chief disadvantage in American practice seems to be bottom trouble, although this could probably be reduced greatly by intelligent operation.

CHAPTER VI

THE COLD SCRAP PROCESS—GENERAL MELTING PRACTICE

Charging—Melting—Slugging Off—Preliminary Recarburization—The White Slag—Finishing the Heat—Adjusting Temperature and Tapping

The manufacture of basic electric steel by the cold scrap process consists of charging the scrap and slag-making materials, melting this charge under conditions more or less oxidizing, removing the slag formed during the melting operation, recarburization, if this is necessary, and finishing the heat by refining under a deoxidizing or white¹ slag. There are a number of variations in basic electric furnace practice the principal of which are: (1) Melting with complete oxidation, (2) melting with partial oxidation and (3) melting without oxidation. In addition many of the complex alloy steels need special treatment in melting. It is essential to a clear understanding of melting practice, that we describe first and in detail the method of making a heat. After this has been presented and the chemistry of the whole process thoroughly understood, then the variations in practice applicable to different grades of steel can be reviewed more intelligently. Consequently, the present chapter and the next will be devoted to a general description of the process and the discussion of the variations in melting practice delayed until these first essentials are dispensed with.

¹ White slag is a general term used to describe the final electric furnace slag. The term is not, strictly speaking, correct as in the best practice the slag ranges from light to dark gray in color. In the following pages the author will make use of the terms "white lime" and "carbide" to describe the common variations of the electric furnace final slag, using the term "white" in its usual sense to denote the final slag of the process irrespective of its color or character. "White" was applied to the final slag a number of years ago probably because, due to absence of oxides and due to the high percentage of lime it was much lighter in color than the slag from any other steel-making process and to distinguish it from the first electric furnace slag which is brown or black and is consequently known as the black slag. Therefore, if the reader will remember that black slag and white slag denote the first or oxidizing and final or deoxidizing respectively, without reference to the slag composition or condition, no misunderstanding in terminology will occur.

The operation of the electric furnace on cold scrap charges may be divided into two periods, very distinct chemically, the oxidation period and the deoxidation period. The former may be subdivided into three major operations, charging, melting and slagging. The latter also takes place in three steps, recarburization, making the slag and finishing the heat. In addition to these there are a number of minor operations, taking tests, determining temperature, etc., which are each important and enter vitally into the final quality of the product.

It is well to emphasize here that the three major variations discussed in Chapter VIII are almost wholly variations in the first or oxidizing period, in all three instances the process of deoxidation remains practically the same. So, to avoid too much repetition we will in the present chapter lay most emphasis on the deoxidation period and pass over the oxidation period briefly.

THE OXIDATION PERIOD

In the oxidation period the scrap is charged and melted, the liquid bath when melting is complete, is then handled in a manner depending on how far oxidation has proceeded and the kind and quality of steel to be made. This period is from 2½ to 4 hr. in length for the average 6- to 8-ton heat and consists as we have already seen of charging, melting this charge and removing the slag formed during the melting period.

CHARGING

The method of charging is practically the same, regardless of how far oxidation proceeds, with the exception that the amount of limestone and ore is varied and that slightly different grades of scrap are used. Upon the correct charging of the furnace depends the rapidity of the melting. The method of loading the scrap into the furnace is so different from the same procedure in open-hearth practice that it warrants an extended discussion.

Charging the Slag-making Materials.—After the necessary repairs have been made to the furnace, charging is commenced. Between 100 and 800 lb. of limestone¹ are charged directly upon the bottom of the furnace. The amount varies with the melting practice and the character and composition of the charge. If

¹ In this and following pages the amount of limestone and other materials charged refers to the total amount for a heat; in this and the next three chapters for an average cold scrap heat of 14,000 lb.

melting is without oxidation only 50 to 150 lb. of stone are needed; with a clean low phosphorus scrap 400 to 500 lb. will give a satisfactory slag volume and composition, but with dirty scrap and when a considerable percentage of phosphorus is present, 600 to 800 lb. are necessary. A clean stone not exceeding 4-in. mesh should be used. It is even preferable to have it crushed to 1- or 2-in. mesh.

After the stone, oxygen as iron oxide is charged. The amount varies greatly depending upon the melting practice used as we will see in Chapter VIII. In general, for the best practice with average scrap where melting is to be low in carbon, 30 to 60 lb. of iron ore or roll scale are sufficient. If the scrap is dirty or rusty, probably sufficient oxygen is present in the rust, and ore or scale is unnecessary. The amount of oxide added to the furnace with the charge is entirely optional with the melter. Often he is inclined to add part of it to the charge and part when melting is complete. In any case, the oxide addition should be kept to a minimum, using only that necessary to complete the oxidizing reactions required by the practice used.

Contrary to the usual opinions there is little to choose between iron ore and roll or forge scale as a source of oxygen. If ore is used it should be a good grade, low phosphorus hematite. Scale contains more oxygen than ore but often contains considerable sulphur. The disadvantages of the sulphur in the scale and the phosphorus and earthy gangue in the ore just about balance each other. It will be shown later that probably the best source of oxygen is manganese ore. The use of this material in the melting period should become universal.

Charging the Scrap.—Following the limestone and ore, the heavy scrap is charged. While the electric furnace does not operate efficiently on the heavy melting scrap used universally by the open hearth, each heat can accommodate two or three large pieces. The opportunity is always taken to charge one or two small scrap ingots or butts weighing from 500 to 1,500 lb. each.¹ Following the heavy material which is charged with a peel,² medium scrap is charged. This material forms the bulk of

¹ As the scrap ingots are usually low in phosphorus they are generally used in the practice of melting with partial oxidation or with no oxidation.

² A peel is a long iron bar with the end flattened like a spade. A roller is placed on the door sill of the furnace, the heavy piece is placed on the peel with a crane and the peel and steel rolled into the furnace by hand and dumped.

the charge for the small electric furnace. It may be almost anything, billet or bar crops, boiler plate, scrap forgings, rail ends, ad infinitum; and country mixed.¹ In melting with complete oxidation, country mixed is used for two-thirds to three-fourths of the charge. After the medium scrap is charged, any fine scrap is placed on top.

The charging of the fine scrap last is unique with the electric furnace. The advantage of this method is: The fine material tends to fill up the interstices between the rest of the scrap, thus more can be gotten into the furnace; and, as a strongly oxidizing atmosphere is not present, almost all of the oxidation coming from solid oxides, the fine scrap is not excessively oxidized in melting. In addition, the presence of fine scrap is conducive to good contact and rapid melting.

It often happens that the charge will be a little too bulky to get into the furnace at once. In this case 1,000 or 2,000 lb. of a scrap most easily handled are kept aside and shoveled rapidly into the furnace after melting has progressed far enough so that room is available.

Charging Labor.—Charging the small electric furnace is nearly always done by hand, the scrap is loaded in through both side doors. In many plants the scrap is brought in from the yard in narrow gage pan cars. After arriving in the melt shop these are weighed, the pan is picked off the trucks, transferred to the furnace floor by a crane and dumped beside the furnace.

The time spent in charging is rarely less than 30 to 40 min., often it is more than an hour. One plant speeded up charging by hiring six burly laborers as a charging gang. These six did nothing else. They were paid a rate of 2 cents an hour more than the plant laborers and in addition received a bonus. If they charged a furnace completely in less than 30 min. an extra premium was paid, for 30 to 40 min. the premium was less, 40 to 50 min. still less and for more than 50 min. the men received no premium. The gang handled four 6-ton Heroult furnaces. By this system of charging, the time was cut from an average of 1 hr. to about 35 min. per heat. This was equal to 40 hr. saved in a month or the equivalent of seven or eight additional heats for each furnace.

The new 7-ton Heroult just designed² goes one step farther in reducing charging time. By a new arrangement of electrode

¹ See p. 43.

² *Iron Age*, vol. 109, p. 325, Feb. 2, 1922. See also p. 84.

control, the electrodes may be lifted almost completely out of the furnace. Charging may then be done mechanically through the doors. Heretofore, the most serious objection to mechanical charging was the possibility of damage to the electrodes. In the older type furnaces, raised as high as possible, they still extended as much as $1\frac{1}{2}$ to 2 ft. below the roof. Careless charging by which heavy pieces of scrap were thrown against the electrodes would break them off easily. The new design eliminates this chance of breakage.

MELTING

Preliminary Melting.—As soon as charging is completed, the doors are closed and the power turned on. If the scrap was charged compactly and is not too dirty or rusty automatic electrode control may be thrown on at once. It is usually desirable to operate the furnace with hand control for a period sufficient, 5 to 15 min., to insure good contact and until the electrodes bore their way well down into the charge.

The violent power fluctuations come during the melting period and are due to erratic arcing and to making and breaking of the contact between the electrodes and the scrap. These fluctuations cease to a great extent when there is a sizable pool of molten metal under the electrodes. The electrodes during the first part of the melting period move up and down erratically; their general direction, though, is downward. In the first 45 min. of the melting period they will bore through the scrap until they reach the bottom of the furnace. This is the danger point. It occasionally happens that, due to the charge being piled somewhat loosely in the center of the furnace, only a small amount of molten metal has collected by the time the electrodes reach the bottom. In this case the electrodes may arc almost directly on the bottom and wear a large hole in the refractories. This may also occur when one of the electrodes finds less resistance to its boring through the charge and reaches the bottom first.

As soon as there is a pool of molten metal beneath each electrode, their general movement is upward as the scrap in the vicinity melts and augments this pool. At the end of 2 hr. often sooner, all of the charge in the center of the furnace is melted. It is still cold and somewhat mushy and there is a ring of white hot pasty scrap around the banks. The furnace is kept

on high power to bring the temperature up to facilitate and speed up the final melting and the oxidizing reactions.

Pushing In.—After about 2 hours "pushing in" may effectively hasten melting. By means of bars (1 in. round or square, 10 to 16 ft. long) the chunks of pasty scrap may be pried off the banks, sliding down into the molten bath. Pushing in, although a very hot and disagreeable job is advantageous for two reasons: (1) It hastens melting and (2) it keeps the temperature down, by precipitating partly solid scrap into the molten metal, and thus aids dephosphorization. After the charge is completely melted and slag formation is complete, more ore or scale is added, if the melter deems this to be necessary, and the bath stirred to determine temperature. For this purpose, the end of a long round bar, $\frac{5}{8}$ or $\frac{3}{4}$ in. in diameter, is pushed well down into the molten bath and moved gently back and forth describing an arc of about 60 deg., until the end in the furnace is melted off. The bar is removed and examined. A pointed end denotes a cold metal; if the end is nicked and ragged the metal is too hot but if the rod is melted off leaving a clean square end the temperature is just right.

As soon as the bath is completely molten and all of the stone has come to the top, the first test is taken and preparations are made for slagging.

Taking the First Metal Test.—The preliminary¹ test is a small amount of metal removed from the bath, cooled, drilled and analyzed immediately by the chemical laboratory. It is a test, the chemical composition of which as reported to him, enables the melter to control exactly the composition of his steel in the furnace. The mechanism of taking the test and handling it rapidly in the laboratory has been described in detail in the author's other work² and will be repeated briefly here.

One side door of the furnace is opened about 12 in.; the first helper then introduces a spoon, with a bowl approximately 3 in. in diameter and $1\frac{1}{2}$ in. deep having a handle 10 to 14 ft. long, into the furnace. By an up-and-down movement followed by a horizontal skimming motion through the slag, the bowl and about 2 ft. of the handle become covered with a thin layer of slag that chills immediately. This is known as "slagging the spoon" and prevents molten metal from fusing onto the metal bowl and handle.

¹ Also known as a quick test or furnace control test.

² "Technical Analysis of Steel and Steel Works Materials," McGraw-Hill Book Co., pp. 120-122, 1923.

After the spoon is slagged, the furnaceman inverts it, reaches well down into the metal, turns it, and withdraws a spoonful quickly taking it from a point as near as possible midway between the surface and bottom and between electrodes and banks.

As soon as the spoonful of metal is withdrawn from the furnace a helper quickly scrapes the slag off the top of the metal in the bowl using, for this purpose, a wooden paddle. The metal is poured rapidly into the mold or test cup shown in Fig. 30.

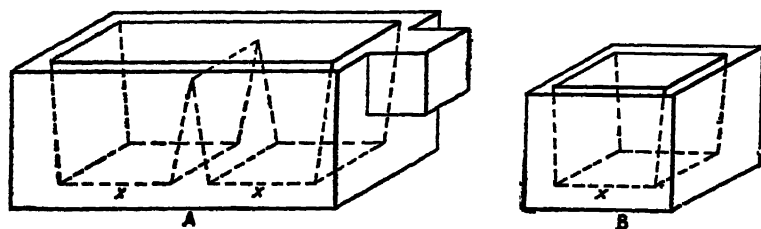


FIG. 30.—Two forms of preliminary test molds.

As soon as it chills, which is almost immediately, the test is knocked out of the mold and cooled rapidly. Some grades of steel may be water quenched, some must be air cooled and others must have a slight lime anneal.¹ The test is then rushed to the drill room where the scale is ground off the bottom surface of the piece (X, Fig. 30). Drillings are then taken at the point X in Fig. 30 and delivered to the laboratory for analysis.

Time Taken by Preliminary Analyses.—With a well organized laboratory, the time expended on preliminary analysis is very short. The furnaceman usually takes his first test just as soon as his bath is completely molten. In some cases where furnace practice is well standardized, he may take it a few minutes before the bath is entirely molten. Five minutes is sufficient to take the test, drill it and deliver the drillings to the laboratory. By estimating, the approximate amount of phosphorus, accurate enough for furnace control, can be reported to the furnace in 10 min. Thus, by the time preparations for slagging are complete, the phosphorus percentage is reported. The carbon and manganese results follow shortly after the phosphorus, 5 to 10 min. additional being sufficient to complete these two elements. Slagging is hardly under way before the melter knows the exact composition of the molten bath.

¹ *Loc. cit.*, pp. 131-133.

It is always advisable for the melter to wait for his analysis before starting to slag off his heat, although after working a furnace for some time and knowing his scrap well, he often takes a chance and goes ahead with the slag removal as soon as melting is complete and the bath sufficiently hot. He will be about half through when the results are reported; it is not too late then, if necessary, to stop slagging and work the carbon, phosphorus or manganese down further if absolutely essential to the final composition.

About the time slagging is complete the nickel percentage will be known, say 15 min. after the carbon and manganese were reported. Usually the laboratory has from 30 min. to 1 hr., to run alloys on the first preliminary test without delaying furnace operations any. Phosphorus is the most important element with carbon a close second. It may or may not be necessary to know the manganese at once; most melters however, require these three elements in 15 to 20 min. after they take the test, with nickel reported 15 min. and chrome reported 30 min. later.

SLAGGING OFF

We have, at the end of the melting operation, the bath of molten metal covered by a thin watery slag. The metal should be fairly hot; if not, high power is applied until the temperature raises to the proper point (2,900 to 2,950 deg. F.). The melter, in most cases, is heating up his bath during the 10 or 15 min. interval that the first metal test is in the laboratory. As soon as the phosphorus percentage is reported, in some cases a few minutes before if he is sure of his metal, slagging is started.

Mechanism of Slagging.—To the front or tapping door¹ of the furnace is attached a weight which will hold it wide open during slagging. The furnace is now tilted very slightly, just enough for the slag to reach the door and run out into the pit in a thin stream. After as much has run off as will, the power is turned off and the electrodes raised. The first helper then introduces a rabble or skimmer² into the front door, and by a raking motion scrapes the slag off the metal and out the door into the pit.

¹ Some are furnaces have a back door through which slagging and other furnace operations are carried out.

² The rabble, or skimmer as it is sometimes called, is constructed like a hoe; a piece of $1\frac{1}{4}$ in. plate about 6 by 8 in. being set on the end of a handle 12 to 14 ft. long. The rabble weighs in the neighborhood of 30 lb.

To assist the first helper in slagging off, the second and third helpers rake the slag from the back of the furnace to the front using for this purpose long green saplings introduced through each side door. To remove the last traces of slag, about 100 lb. of lime are thrown into the furnace. This floats on the bath as a thick mass and collects any small amounts of slag not already removed. The whole mass is then poled to the front and raked out the door.

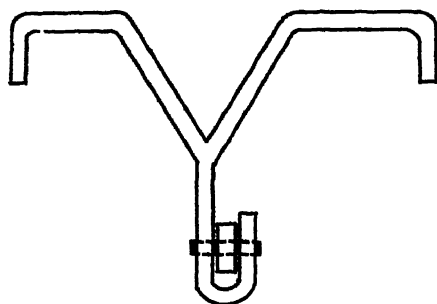


FIG. 31.—Skimmer holder for slagging.

Precautions in Slagging.

Slagging a 6-ton heat is a hot and disagreeable job at the best, but it can be made easier by a little attention to detail. It is possible, when the slag is the right consistency, to pour off more than half,

only using a rabble for the last part. The melter soon learns the proper fluidity to attain in order to lessen the manual labor connected with raking off the slag and adjusts his slag accordingly; after melting is complete and the temperature is all right. To thicken, he adds a few shovelfuls of lime; to thin, one or two small shovelfuls of fluorspar will put the slag in proper shape. It is necessary here that the furnace be tilted at just the right angle. If tilted a little too much, an appreciable amount of metal will be lost, running out with the slag.

Most melt shops have constructed a Y-shaped steel framework which fits on the front door of the furnace. A roller is attached to the bottom section of the Y (see Fig. 31) on which the skimmer moves in and out of the furnace with little effort.

The long saplings used for poling the slag to the front door are preferably of green wood. If these are not obtainable, dry poles may be used but should be dampened before use.

A convenient method of slag disposal is to place a chain some 8 to 10 ft. long in the pit and rake the slag onto the chain. After the slag is solid, an hour or two, the two free ends of the chain are brought together and the solidified slag lifted bodily out of the pit with a crane.¹

¹ Slag pans are commonly used.

After slagging is complete, the metal is ready for the final treatment, recarburizing of the bath if necessary or desirable and deoxidation and desulphurization which makes up the final period of the practice.

THE DEOXIDATION PERIOD

The deoxidation period may be conveniently divided into three operations, preliminary recarburizing, making the slag and final deoxidation. The first, preliminary recarburization is not recommended as producing the best grade of steel—this will be discussed later—although this practice is still used extensively. Whether recarburization is made at this point or not, the other two operations are the same for all furnace practice; no matter how the heat is melted, it should be deoxidized by the same type slag applied in the same way. In the deoxidation period all additions of ferro-alloys are made. It is obvious that here is one decided advantage of the electric process, easily oxidizable alloys may be added directly into the furnace with no loss instead of into the ladle, as is common and necessary in most cases in the Bessemer and open hearth. The addition of these alloying elements directly to the metal in the furnace tends to produce uniformity as each alloy has plenty of time allowed for its complete and thorough distribution.

The first step in the final period is recarburization.

PRELIMINARY RECARBURIZATION

Method of Recarburizing.—After removing the oxidizing slag, we have in the furnace a bath of bare metal. If desired or if necessary, recarburization may be made here, the bare metal quickly absorbing any carbonaceous material added to it. For this purpose, either coke, anthracite coal or broken pieces of electrodes is ground to a powder (ten mesh or finer), and is weighed into paper bags holding about 10 lb. each. The bags are shoveled into the furnace being placed as near the center as possible, preferably directly under the electrodes.

The best material for recarburization on the bath is electrodes. There is always some accumulation of scrap electrodes, butts, broken nipples, etc., in the melt shop. These are broken up to about 2 in. mesh with a sledge hammer and fed into a crusher which delivers them at 10 mesh or finer. Electrodes have the

advantage of a lower ash than coke and have, of course, no volatile matter as has anthracite. Coke breeze, while cheap, is not desirable on account of the high ash.

Amount of Recarburization.—When this method of bringing up the carbon is used, sufficient is added, if carbon steel is made, to result in a percentage three to five points below the minimum requirement for that particular heat. When alloy steel is the product, the carbon is brought up to a point low enough so that when all alloy additions are in the furnace, the carbon will be a little below the minimum. With a hot bath, about 70 per cent of the weight of the electrodes added is absorbed by the metal as carbon. With crushed coke this figure is too high, approximately 60 per cent being taken up by the bath. Thus, if a heat is melted down to .15 per cent, and the requirements are .60 to .70 per cent sufficient recarburizer is added to bring the metal up to .55 per cent carbon. If the charge was 15,000 lb., and 4 per cent was taken as the furnace loss, a simple calculation¹ would show that 83 lb. of recarburizer are necessary.

The power may or may not be on while recarburizing. This depends on the condition of the bath; if too cold, the current is thrown on as soon as the oxidizing slag is removed; if hot enough² to absorb carbon readily, it is desirable to keep the electrodes raised and the power off until the recarburizing reaction is complete.

It is never advisable to add more than 125 to 150 lb. of recarburizer to the bare bath in a 6- to 8-ton heat. In other words, do not try to bring the carbon up more than 60 to 70 points.³ Preliminary recarburizing, of doubtful value in any case, becomes increasingly harmful as the amount of recarburizer added increases. About the only justification of excessive preliminary recarburization is in the manufacture of synthetic pig iron and electric furnace washed metal from steel scrap. This brings us to the disadvantages of recarburizing.

Disadvantages of Preliminary Recarburization.—The greatest disadvantage of recarburizing with electrodes or other form of

¹ Four per cent of 15,000 lb. is 600 lb. 15,000 lb. minus 600 equals 14,400 lb. in the furnace. If .15 per cent is contained carbon and .55 per cent the desired percentage, then .40 per cent must be added in the form of recarburizer or 58 lb. of carbon. Since 70 per cent is absorbed 83 lb. of crushed electrodes are added.

² The hotter the metal the more rapid and complete the carbon absorption.

³ The manufacture of synthetic pig iron is an exception to this.

carbon after the oxidizing slag is removed, or any other time, for that matter, is that deoxidation is made more difficult by the large amount of solid non-metallic impurities and gases introduced by the operation. Recarburization is only necessary when the heat is melted low in carbon, in other words, when melted with complete oxidation. As soon as the carbon is added, a vigorous reaction ensues, by which the dissolved ferrous oxide in the bath is deoxidized with the formation of large volumes of carbon monoxide gas causing for a time a very wild metal. This evolution of gas is of course the result of an over-oxidized metal. The ferrous oxide is a factor always present where much ore or scale was used and as it must be gotten rid of in any case, it is probably better to accomplish this by carbon early in the process than later in the deoxidation period. However, it is a fact, that the evolution of large volumes of carbon monoxide here results in a metal containing much dissolved gas that is later removed with more-or-less difficulty.

In addition, the carbon absorbed by the bath carries with it from 10 to 15 per cent ash or in the case cited on a previous page, where 83 lb. of recarburizer were added, 8 to 10 lb. of solid non-metallic impurities are added in a finely divided form. Obviously, in a process that, in most of the refining, has elimination of solid non-metallic impurities as the principal object, the addition of 8 to 10 lb. of finely divided earthy substances is highly undesirable.

We may say then, that preliminary recarburizing on the bath after the oxidizing slag is removed has few advantages and many disadvantages. Its principal advantage is cheapness as the cost of scrap electrodes or coke breeze is practically nil when compared with the cost of low phosphorus pig iron or of washed metal. We will see in a later chapter that melting with complete oxidation with recarburization as here described, is the cheapest and most fool-proof process and is consequently favored by a large majority of plants and results in most instances in an inferior product. Aside from the cost, it removes most of the dissolved ferrous oxide. Here the advantage is doubtful; if the heat was melted correctly it would not be over-charged with FeO .

The disadvantages are: (1) Large volumes of carbon monoxide gas resulting from the recarburizing reactions, part of which is later gotten rid of with difficulty, and (2) the introduction of

an appreciable amount of solid non-metallic impurities in a form not easily removable.

Quieting Wild Metal after Recarburization.—The direct result of recarburization after the oxidizing slag is removed is a wild bath, so, after the carbon is all added, the furnaceman stirs his heat well to insure thorough mixing and adds two or three small shovelfuls of crushed ferrosilicon (50 per cent) scattering it over the entire surface. Twenty to twenty-five pounds are sufficient, and will prevent the excessive boiling which in an overcharged furnace, may send some of the metal out the doors.

In some plants the furnaceman will add ferromanganese to the metal either before or after recarburizing. This alloy of course deoxidizes any oxides present and makes the bath more quiet. It should not, if possible, be added before recarburization as a boiling bath absorbs carbon much more readily and efficiently than a quiet one. The addition of ferro-manganese at this point of the process is of doubtful value, as the manganese oxide which forms and rises to join the slag must be reduced to the metal before the slag and metal can be deoxidized completely. If silicon is used, its reaction product forms a permanent part of the final slag. We will take this up again in another section.

The metal in the furnace, which has been melted with a variable amount of oxidation depending upon the grade of steel to be made and the knowledge and skill of the melter, has had the first slag removed and has been recarburized if necessary or desirable, and quieted. It is now ready for the final step in the process, making the white slag and deoxidizing the bath.

THE WHITE SLAG

The electric furnace white slag is composed of lime, coke and fluorspar or silica sand. In the best practice, as we shall see later, fluorspar is used in preference to the acid material. The proportions of the slag-making materials vary greatly with the practice used, the kind of steel made, and the ability of the furnaceman. Two varieties of white slags are common in best practice, the white lime slag used only in making low carbon steel and the carbide slag used in most plants for all other grades.

The reader should understand here that there is no sharp dividing line between the white lime slag and the carbide slag. The author is accustomed to distinguish electric furnace white

slags that are rather gray in color and smell distinctly of acetylene when moistened with water, as carbide slags and all others as white lime slags. A possible dividing line is 1 per cent calcium carbide. The slag may of course, be gray in color, have plenty of carbon present and still have no carbide. All of the carbon in this case is uncombined, temperature or other conditions were perhaps not favorable for carbide formation. Again, it is possible to detect the odor of acetylene in a slag when only a few tenths of 1 per cent calcium carbide is present. Although the whole thing is a matter of experience, it may be said that the carbide slag leaves no doubt as to its composition, the characteristic odor of acetylene is fairly prominent when the percentage of calcium carbide approaches 1.

For a general average, it may be said that the white lime slag is composed of 8 to 16 parts of lime, $\frac{1}{2}$ to 1 part of coke and sufficient, 1 to 4, parts of fluorspar. The carbide slag is made up of 5 or 6 parts of lime, $1\frac{1}{2}$ to 2 parts of coke and sufficient, $\frac{1}{2}$ to 2, parts of spar. No hard and fast rules can be laid down for the proportions of slag materials. It is here that the judgment, experience, and intelligence of the melter comes actively into play. He varies the amount of lime, coke and spar to attain a definite result, a slag containing sufficient carbide to deoxidize his heat thoroughly but still not so strong that carbon absorption will be beyond control.

We will reserve discussion of the relative merits of the white lime slag and the carbide slag until later, taking up here the mechanism of slag formation, citing a condition and composition in average daily practice.

Making the Slag.—For the average 16,000-lb. heat, 500 to 600 lb. of lime, 150 to 200 lb. of coke and 100 to 150 lb. of spar are mixed thoroughly on the shop floor and after recarburizing is complete, if this is the practice followed, all is shoveled into the furnace as rapidly as possible. The doors are now closed, preferably luted with fireclay to keep the furnace nearly air tight and high power turned on. The furnace is left quietly for 20 to 45 min. to facilitate slag formation. At the end of this period one door is opened slightly, a spoonful of the slag is withdrawn and after pouring on an iron plate examined. If the slag is brown or brownish-black, it is not deoxidized and more coke is scattered over the bath. If too thick, more spar is added to thin it—this will usually be the case if the lime is high in

magnesia or low in silica; if too thin, lime or even a little crushed dolomite may be added to thicken.

After about 30 min. under high power, sometimes even sooner, the slag should appear fluffy, especially around the electrodes. This fluffing and foaming which is not unlike thick soapsuds spreads gradually from the electrodes to the banks. After 30 min. to an hour, the slag should be quiet, slightly foamy, and under the electrodes very fluid. A sample cooled and examined should be white, denoting the probable absence of more than traces of ferrous and manganese oxides or, preferably, it will be gray due to carbon or calcium carbide. The slag is now deoxidized; it only remains to deoxidize the metal by means of a slag strong in carbide.

The Carbide Slag.—Calcium carbide is formed through the reaction of lime, CaO , and carbon at the temperature of the electric arc. To form carbide in appreciable amounts, a considerable excess of coke must be present. After the slag is white or nearly white, showing that most of the ferrous and manganese oxides have been reduced by the coke, calcium carbide formation if not partly accomplished in the furnace already, is started.

Eight to ten shovelfuls of lime are mixed with half to two-thirds as much coke, and this mixture shoveled into the furnace as close to the electrodes as possible. A shovelful of coke is then scattered over the bath and the doors closed tightly. High power is maintained for 10 to 15 min. longer. The bath and slag are stirred well and a sample of slag taken out of the furnace with a spoon and after solidifying, cooled slowly in water. The color should be dark gray and when wetted it should smell strongly of acetylene. In fact, when a strongly carbide slag is carried,¹ the odor of acetylene from a moistened spoonful should be easily distinguished at a distance of 5 to 10 ft.

Through stirring the metal and slag at intervals of 20 to 30 min., and through the migration of oxide from metal to slag to restore the equilibrium, deoxidation of the steel should be practically complete in about one hour after the slag is strongly carbide. The total elapsed time from the removal of the black slag until deoxidation may be called complete varies from $1\frac{1}{2}$ to 3 hr., depending on conditions and the skill of the furnaceman.

¹ A mill expression; the furnaceman speaks of the metal "carrying the slag."

Other Methods of Building the Slag.—Although it is preferable to mix the slag-making materials well before adding to the furnace, many melters build their slag on the bath. This procedure is used and is perhaps the best, all things considered, in the larger hot metal furnaces; but is not advisable in the cold scrap process. The advantage of building the slag on the bath instead of mixing on the shop floor is that less carbon is absorbed by the metal. The principal disadvantage is the difficulty of forming carbide uniformly throughout the whole body of the slag. The mechanism of slag-making in the furnace is something like this: 400 to 600 lb. of lime are shoveled into the furnace. High power is immediately thrown on and the furnace sealed for 15 min. The lime is now thoroughly heated and has gathered into itself all of the oxide previously floating on the bare metal. Fluorspar or silica sand is now shoveled in, 100 to 200 lb. being used. The amount necessary varies; enough is added to attain the required fluidity. The slag is now dark brown from the oxides present and is sufficiently fluid. The coke may now be added; 50 to 150, even 200 lb. are shoveled in and scattered over the surface of the slag. The slag should be deoxidized in a few minutes after the coke addition. It is now only necessary to seal the furnace and wait for carbide formation to take place.

In this method of slag-making, the ultimate result is the same, although many melters consider that it is harder to maintain a considerable percentage of carbide when the slag is built in the furnace.

Slag Additions during the Remainder of the Heat.—After the correct slag condition is attained, it remains to keep it in proper shape during the rest of the heat. Roughly, it takes 30 min. to free the slag from FeO and MnO , it takes 15 min. more to promote carbide formation. The balance of the deoxidation period, 1 to 2 hr. is taken up in making alloy additions, adjusting chemical composition and temperature and completing the deoxidation of the metal. During this period the slag must be kept uniformly carbide and thus strongly reducing. This is no little task and requires skill and experience on the part of the melter. We will see in a subsequent chapter how many untoward influences, atmospheric oxygen, small portions of the bottom coming up, for example, may affect the condition of the slag. Consequently the final hour is a continued struggle to keep the slag in shape. This is done by additions of lime, coke or spar either alone or mixed

as the occasion requires. By the combination of coke additions, maintaining the proper fluidity and excluding atmospheric oxygen as much as possible from the furnace, the slag may be kept in good condition right up to the moment of tap.

FINISHING THE HEAT

After the slag has been deoxidized and is strongly carbide, it is necessary to keep it in this condition, make alloy additions and adjust the composition and temperature to that necessary for the grade of steel to be made. If the slag is kept in shape, deoxidation should proceed nearly automatically and the addition of ferro-silicon should take care of the gas.

While most of the ferro-alloys are not added until the slag is in good shape, one or two may be added early. It is advisable to discuss alloy additions briefly especially those used in the common alloy steels. The steels requiring a special melting practice may be properly discussed by themselves later.

Alloy Additions.—As soon as the black slag is removed and the white slag shoveled into the furnace, nickel may be immediately added, provided the metal is sufficiently hot to dissolve it without being chilled excessively. If nickel scrap is used in the heat, and this is always the case when nickel and chrome nickel steel are made, only a small addition, usually less than 300 lb. must be added. This will not chill the bath to any extent. The other three elements forming a solid solution with iron, copper, cobalt and molybdenum may also be added early in the heat. There is no danger of any part of these four alloys being lost by oxidation, they immediately dissolve in the molten bath and stay there.

As before noted, part of the manganese is, in some shops, added onto the bare metal when recarburizing. In best practice, however, almost all of the ferromanganese is added as soon as the slag is deoxidized; in other words, 30 to 45 min. after the beginning of the deoxidation period (see Log Sheet 1). With no appreciable amount of oxide in the slag, all of the ferro-alloy goes directly into the metal. The small amount necessary to give the required final percentage is added as soon as the results on the final preliminary tests are received (Log Sheet 1).

Silicon in the form of the 50 per cent alloy is, in the majority of plants, added about 10 min. before tap. The advisability of making the addition so late is questionable, as too short a time is

available for the reaction products to leave the steel. Silicon is preferably added partly after the slag is completely deoxidized, another part about 30 min. before tap, and the final third about 10 or 15 min. before tap.

Chromium¹ may be added as soon as desired after the slag is free from oxides. If the bath is not completely deoxidized, some of this alloy will be oxidized and will pass into the slag coloring it green. This color is clearly evident even if only a few tenths of 1 per cent chrome are present. A little powdered coke scattered over the slag will deoxidize the chromium oxide and drive the metal down into the steel.

Vanadium¹ is added before tap after the final silicon addition. Vanadium is very easily oxidized so, for that reason, should not be added until it is certain that no oxides nor carbon monoxide are present in the slag or bath. The ferro-alloy melts easily; by adding it 10 or 15 min. before tap it is certain that all will be melted and thoroughly distributed.

Log Sheet 1, a condensed furnace log of a heat of nickel chrome steel shows the time of adding ferro-alloys.

The manufacture of high speed and other special steels will be discussed later. The additions of the alloys for these grades; tungsten, etc; will be taken up then.

Taking the Final Furnace Tests.—Usually one, sometimes two tests are taken during the deoxidation period to determine the progress of the heat and assure the furnaceman that his composition is correct. The melter, knowing the composition of the metal at the moment of slagging, makes his additions accordingly, deoxidizes his slag and then takes out his final tests. It is essential that the slag be completely deoxidized to insure that the bath will remain constant in composition (except the carbon which increases slightly) throughout the rest of this period.

Nickel and manganese are usually added before the tests are taken; an amount sufficient to bring the percentage of these elements up to the minimum required. After they are melted and the heat and slag well stirred, the tests are taken, one from each side door. The mechanism of taking these tests is the same as for the first preliminary test described on p. 117. Duplicate tests are not essential but are advisable as they serve to prevent any possible error or dispute over analysis. One of the final

¹ Ferrochromium (60 per cent) and ferrovanadium (40 per cent) are commonly used.

tests is taken through one side door from a point midway between surface and bottom and between electrodes and banks. As soon as the metal is poured into the test cup, the procedure is repeated at the other side door. Duplicate tests eliminate the possibility of the error, sometimes present, if a test is taken too soon after an alloying addition, from a very cold bath or from a bath that is not well stirred before taking the test. By duplicate tests local segregation or variation in the bath will be detected at once.

One precaution is worthy of attention in the procedure of taking the final furnace tests. They should not be taken immediately after a coke addition is made to the slag. It often happens that when a shovelful or two of coke is scattered on the bath the powder will lie suspended for a considerable period of time—for 5 to 10 min.—when far enough from the electrodes to avoid the action of the arc. In slagging the spoon, free coke may become entrapped to be later dissolved in the spoonful of molten metal taken for the test. Several times in the author's experience, final furnace tests were found to contain from 5 to 10 points more carbon than was actually in the bath. If watched carefully, this possibility of error may be completely avoided.

Calculation of the Chemical Composition.—For the benefit of those readers who have not had the opportunity to watch electric furnace practice at close range, we will explain in detail the method of calculating the amount of ferro-alloy and other additions to the furnace, and the procedure in controlling the analysis. For illustration, we will take the heat illustrated in Log Sheet 1. For this heat the melter has ordered a miscellaneous assortment of scrap with sufficient nickel-bearing material, so he will have about 1 per cent in his bath when melted. The total charge is 15,700 lb. Approximately 4 per cent is allowed for furnace loss. The charge will therefore be close to 15,000 lb. The scrap is melted with a limited amount of oxidation to leave some residual carbon and manganese in the bath.

The melt-down test showed .010 per cent phosphorus, .13 per cent carbon and .17 per cent manganese. No recarburization on the bath is necessary as the 12 to 15 points between the composition at slagging and the requirement will be met by the carbon contained in the ferro-alloys, picked up from the slag and if this is not sufficient, a few points may be secured by washed metal.

Accordingly, the melter slags off the heat and immediately adds his white slag. At 10:15 a.m. he receives the nickel percentage

from the laboratory. If he aims at a final percentage of 2 he must add to the furnace the difference between 2 per cent and what he already has or .97 per cent. This is 1.03 per cent. The number of pounds of nickel is 1.03 per cent of 15,000 or 15,000 multiplied by .0103 which is equal to 155. Since the nickel is 99 per cent pure, he must add 155 divided by .99 or 157 lb. From Log Sheet 1 we see that he added 160 lb. at 10:30 a.m.

LOG SHEET 1.—CONDENSED FURNACE LOG SHOWING ALLOY ADDITIONS AND DISTRIBUTION OF TIME IN MAKING A 7-TON HEAT OF NICKEL-CHROME STEEL

	C	Mn	Si	S	P	Ni	Cr
Analysis ordered . . . . .	.25	.40	.15	.025	.025	1 75	.40
	.35	.60	.25	less	less	2.25	.60
6:10 a.m.	Previous heat tapped.						
6:20 a.m.	Bottom repaired.						
6:20 a.m.	Began charging.						
7:00 a.m.	Scrap all charged, 15,700 lb.						
7:00 a.m.	Power on.						
9:05 a.m.	Nearly melted, began pushing in.						
9:30 a.m.	All melted, first test taken.						
9:35 a.m.	Slag thick, added fluorspar.						
9:40 a.m.	Began slagging; result first test; P. .010 per cent.						
9:50 a.m.	Results, first test: C .13 per cent; manganese .17 per cent.						
9:55 a.m.	Slag off; no recarburizer required.						
10:00 a.m.	White slag all on; furnace on high power.						
10:15 a.m.	Results first test: nickel .97 per cent.						
10:30 a.m.	Slag melted, almost white; result, first test, Cr .17 per cent.						
10:30 a.m.	Added nickel (99 per cent), 160 lb.						
10:40 a.m.	Slag white; added ferromanganese 50 per cent, 50 lb.						
10:50 a.m.	Last tests taken.						
10:55 a.m.	Slag carbide; added ferro-silicon 50 per cent, 25 lb.						
11:05 a.m.	Results, last test: C .15 per cent; manganese .41 per cent.						
11:10 a.m.	Added ferrochrome 6 per cent C, 66 per cent Cr, 75 lb.						
11:10 a.m.	Added ferro-manganese 50 per cent, 20 lb.						
11:10 a.m.	Added washed metal, 200 lb.						
11:10 a.m.	Added ferro-silicon 50 per cent, 25 lb.						
11:15 a.m.	Results, last test, nickel 2.05 per cent.						
11:20 a.m.	Added nickel (99 per cent), 10 lb.						
11:20 a.m.	First heat test; temperature hot.						
11:25 a.m.	Added ferrosilicon (50 per cent), 25 lb.						
11:30 a.m.	Second heat test; power off.						
11:40 a.m.	Tapped.						
	C	Mn	Si	S	P	Ni	Cr
Final analysis . . . . .	.30	.51	.183	.016	.017	2.08	49

At 10:40 a.m. his slag is practically deoxidized so he adds the bulk of the ferromanganese. He aims at .45 per cent or just above the minimum. He had, when melting was complete, .17 per cent. Therefore the bath lacks .45 minus .17 or .28 per cent. Now, .28 per cent of 15,000 ($.0028 \times 15,000$) will give 42 lb. of manganese which must be added to bring the percentage up to .45. Since the ferromanganese used contains 80 per cent manganese, the 42 lb. is equivalent to 42 divided by .80 or 52 lb. In the heat illustrated in Log Sheet 1 the melter has added 50 lb. at 10:40 a.m. After the manganese is dissolved, the tests are taken out at 10:50 a.m. and the results on carbon and manganese received at 11:05 a.m. These are: Carbon .18 per cent, manganese .41 per cent.

Let us see for a moment where he gets .18 per cent carbon. When melted there was .13 per cent in the bath. It is common practice to assume that the metal picks up about 2 points of carbon per hour from the carbide slag. The manganese added contained 7 per cent carbon or 7 per cent of 50 lb. or 3.5 lb. of contained carbon. The nickel contained .35 per cent or .35 per cent of 160 lb. or .6-lb. of carbon. With the alloys already added 4.1 lb. of carbon have also been added. This is equal to 3 points (.03 per cent) with a charge of 15,000 lb. ($4.1 \div 15,000 = .0003$ or .03 per cent). Three points from the alloys and one point from the slag added to the .13 in the bath will give .17 per cent. In Log Sheet 1 we see that he actually has .18 per cent.

Final Calculations.—The melter had calculated on having .45 per cent manganese present but from the laboratory results finds he has .41 per cent. A little more must be added to be on the safe side so at 11:10 a.m. he adds 20 lb. of the ferro-alloy or 16 lb. of contained manganese. This is equivalent to $16 \div 15,000$ or .0011 or .11 per cent. The heat should finish with .52 per cent manganese. Log Sheet 1 shows the final analysis to be .51 per cent.

Because a miscellaneous lot of scrap was charged, the laboratory was required to determine chromium on the melt-down test. They found .17 per cent, reported at 10:30 a.m. The slag was white at 10:40 a.m. so the ferrochrome could have been added then. In this case, however, making a comparatively low carbon steel, the melter waited for the carbon result on his final furnace tests before adding this alloy. In case something had happened

that the carbon was too high on this test, say .28 per cent instead of .18 per cent he could have used low carbon ferrochrome and thus saved the heat. Although it is desirable to add the chrome as early as possible, this is more important in the higher chromium steels, ball-bearing steel for example, where 1.50 per cent is present.

He therefore, at 11:10 a.m. added 75 lb. of ferrochrome. This figure is arrived at as follows: .50 per cent, the average required percentage, minus .17 will give .33 or the percentage to be added. Now, .33 per cent of 15,000 lb. ($.0033 \times 15,000$) is 50 lb. of chrome. Since the ferrochrome used contains 66 per cent chrome this 50 lb. is equivalent to $50 \div .66 = 75$ lb. Now this ferrochrome contains 6 per cent carbon so by adding 75 lb. he is adding 4.5 lb. of carbon or 3 points (.03 per cent). ($4.5 \div 15,000 = .0003$). The last test showed .18 per cent; the melter has since added 20 lb. of ferromanganese which will give .01 per cent and 75 lb. of ferrochrome or .03 per cent carbon, consequently he should now have $.18 + .03 + .01 +$ a possible .02 from the slag or a total of .24 per cent carbon. At 11:15 a.m. the melter receives the nickel percentage from the laboratory on his final test which is 2.05. He now has in his bath, either calculated or from the results on his final tests:

Carbon, .24 per cent (last test and calculated from additions).

Manganese, .52 per cent (last test plus the added ferromanganese).

Nickel, 2.05 per cent (last test).

Chrome, .50 per cent (first test plus added ferrochrome).

It will be noted that all of the elements except carbon are well within the required limits. The carbon still needs slight adjustment so at 11:10 a.m. he adds 200 lb. of washed metal. This material contains about 3.50 per cent carbon so 200 lb. will contain 7 lb. of carbon or .05 per cent. The final percentage should be .29 if no more is picked up from the slag. Actually, as we see in Log Sheet 1, .30 is the final percentage.

Although the nickel already in the bath is all right, the melter adds 10 lb. more at 11:20 a.m. This he figures will result in a percentage of about 2.10. Most melters aim to keep the nickel on the high side¹ if possible. If, as happens rarely, an error

¹ A mill expression; if the percentage of an element is near the upper limit it is on the high side, conversely if near the lower limit it is on the low side.

occurs, from the weight of the charge or from some other cause, he figures that a little extra nickel will do no harm. If, in the heat in Log Sheet 1 the nickel should finish about 1.70 per cent the customer would probably refuse to accept it, if, however, the final percentage was 2.30 or 2.35 this extra amount would do no harm and the heat could still be applied on the order. For this reason, in quite a number of shops, the melters aim to keep the alloys, especially the nickel on the high side of the required limits.

The composition has now been completely adjusted, all except silicon. With this element, 75 lb. of the ferro-alloy have been added, one third at 10:55 a.m., one third at 11:10 a.m. and the rest at 11:25 a.m. The 75 lb. of the alloy represents 37.5 lb. of contained silicon. In average practice, especially where heats are made as rapidly as the one in Log Sheet 1, the melter figures on about 70 per cent absorption. Thus 26.3 lb. actually goes into the steel or $26.3 \div 15,000$ or .175. In the heat in Log Sheet 1 a little more has been taken up by the metal as it finished .183 per cent (absorption, about 75 per cent).

Influence of the Weight of the Charge on Chemical Composition.—In the previous paragraphs, we have calculated the percentages of the elements and figured the alloy additions using 15,000 lb. as the charge. This was done to avoid too many complications. Also we took 4 per cent as the furnace loss. This amount is by no means constant but varies according to the grade of scrap used. In the heat illustrated in Log Sheet 1, the furnace loss was actually nearer 6 per cent than 4. The melter, through experience, becomes familiar with the scrap he has available and gages his furnace loss according to his experience with the scrap charged. This may range from 2 per cent to as much as 6 or 8 per cent.

In actually calculating the furnace additions, account must be taken of the increase in weight of the charge through these additions. Thus in the heat shown in Log Sheet 1, the melter has an original charge of 15,700 lb. If he allows for a furnace loss of 4 per cent, he will have, when melted, 15,080 lb. He must then take into account the metallic additions thus:

Charge	15,080	Washed metal	200
Nickel	170	Ferrosilicon	75
Ferromanganese	70		
Ferrochrome	75	Total charge	15,670

Thus instead of figuring on a basis of 15,000, as we have done in the previous paragraphs, we should have taken 15,700 as the charge. In this particular charge the loss was more than 4 per cent, so our calculations were correct not considering the additions. In a heat where the amount of additions is small, this does not make material difference. It does influence greatly in some other grades of steel; for example high speed steel where the tungsten, chrome and vanadium additions may amount to as much as 4,500 lb. with a 10,000-lb. charge.

The three furnace logs given in detail in Chap. VIII afford other examples of the method of calculating and adjusting the chemical composition of the heat.

ADJUSTING TEMPERATURE AND TAPPING

After $1\frac{1}{2}$ to 3 hr. under the deoxidizing slag, the refining may be called complete. All additions to the furnace have been made and the chemical composition has been adjusted to the exact point desired. It now only remains to adjust the temperature up or down as necessary to the degree required for the steel being made. When this is accomplished, the ladle is placed in position and the heat tapped.

Temperature at the End of the Deoxidation Period.—Deoxidizing on a hot bath is favored by most furnacemen. A high temperature is favorable to good slag conditions and to rapid completion of the chemical reactions of refining. To facilitate this very hot deoxidation, high power is kept on the furnace for the greater part of the period. After most of the alloy additions have been made the power may be reduced slightly, but in any case at the end of the deoxidation period the bath should be much hotter than that required for tapping. The tapping temperature will vary from 2,850 to 2,950 deg. F. (1,565 at 1,625 deg. C.) sometimes even as much as 3,000 deg. F. (1,650 deg. C.). The temperature in the furnace 20 min. before tap should be about 3,100 deg. F. (1,705 deg. C.). It is therefore necessary, to allow the furnace to cool at least 100 deg. F., sometimes more. To this end, the power is shut off completely, the metal lying quietly in the furnace for 5 to 15 min. At the end of this time, the melter takes his final heat tests.

Method of Determining Temperature.—Melters become very adept at estimating the temperature of a bath of molten metal.

It is common for a furnaceman of long experience to judge temperature to within ± 50 deg. F. Many of them can estimate much closer than this (to about ± 25 deg.).

To determine temperature three methods are used. The first has been described in an earlier section and consists of melting off a bar in the bath and judging the temperature of the metal from the appearance of the end. This method is often used during the progress of a heat but rarely at the end of the process. The other two methods are the pouring test and the set test.

The pouring test is the most popular and is perhaps the best means of judging the temperature accurately if carried out correctly. The test depends on the very obvious fact that the hotter the metal the longer it will stay fluid in contact with cold surroundings. The test spoon is well slagged, is held in the furnace until thoroughly heated and a spoonful of metal withdrawn and poured in a slow stream into a test cup. (Fig. 30, page 118.) The rate at which the metal films over in the cup is, of course, dependent on the temperature. The hotter the metal, the longer time necessary for the film to form. The melter watches the stream of metal closely as it is poured into the mold. A cold metal is thick and sluggish, conversely, when hot, it is thin and watery. Another factor is a possible skull left in the spoon. If this appears, the metal is cold. This last factor is not important because, obviously, it depends to a large extent upon the relative coldness of the spoon and the amount of insulating slag layer between the metal bowl and the steel. It is plain that the pouring test can be only comparative as many factors affect its accuracy. However, it is quite surprising how closely the experienced melter can control his temperature by this means.

The set test attempts to modify the pouring test and determine temperature by eliminating to a degree at least the personal equation. A spoon of definite size is carefully slagged and a spoonful of metal quickly withdrawn from the furnace. The slag on the metal is at once scraped off. The spoon is then held quietly and the time necessary for a film to form is taken with a stop watch. A time of 10 to 11 sec. shows the temperature to be about right; with less than 9 sec. the metal is too cold and with 12 sec. or more too hot.

Determining the Metal Temperature with an Optical Pyrometer.—As, even under the best conditions, the above methods of determining temperature are subject to serious errors, many

attempts have been made to determine furnace temperatures accurately with an optical pyrometer. These efforts have, for the most part, resulted in failure. Direct readings on the slag cannot be taken as the electric furnace slag is at all times considerably different from the metal. Usually it is from 50 to 300 deg. hotter. Readings taken on a spoonful of metal poured into a test mold are erratic as it has cooled considerably from contact with the spoon and air even in the brief time necessary to remove the metal from the bath. However, it is probably in this way that the optical pyrometer will find its greatest use for measuring furnace temperatures.

Attempting to observe bath temperatures by means of a refractory tube has not been successful as few refractories will stand direct immersion in the metal. Even if the tube will stand this immersion, it is almost always partly filled with fumes.

In addition to all of these troubles, additional errors are introduced through lack of black body conditions which are necessary to accurate observations with the optical pyrometer. Because of the errors introduced, the optical pyrometer is not used to any extent in measuring metal temperatures in the furnace being confined mostly to pouring temperatures for which it is better adapted. Consequently, the melter depends on his knowledge and experience to tell him when his temperature is correct.

Judging Deoxidation by the Heat Test.—The heat test poured as above described also constitutes a direct measure of the degree of deoxidation or soundness. If deoxidation has been carried out thoroughly by the carbide slag, and if degasification is completed by additions of ferro-silicon added at 10- to 20-min. intervals late in the deoxidation period, the heat tests should be quiet in the mold with no sparking or no bulging of the upper surface. After the bath has been completely deoxidized and degasified the exposed surface of the solid test piece should be slightly concave or nearly flat and when fractured, no gas holes should be visible.

The appearance of the test in the mold is also an approximate indication of the amount of silicon present. An upper surface that is perfectly flat or a slightly concave denotes a silicon content of approximately .18 per cent. A higher silicon, that is, up to .25 or .30 per cent will show a distinct depression in the surface. This indication is not exact, because it is not absolutely dependent on the amount of silicon, but is a measure of the amount of degasi-

fication accomplished, this degasification being the result of silicon, the manganese and to some degree, the carbide slag.

If, after taking a number of tests, the heat appears to be completely deoxidized and degasified, if the temperature condition is satisfactory, and if the slag is liquid and strongly carbide, the ladle is placed in position and the heat tapped.



FIG. 32.—Tapping a 6-ton heat of electric steel.

Tapping the Heat.—It is desirable to tap the metal completely before the slag. To this end, many of the newer furnaces have either a tapping door with a hole or a spout and skim gate which will permit the metal to flow out before the slag starts. In the older models, both metal and slag would be tapped at once, unless the slag was held back with a skimmer. Most of the old designed doors have been replaced with a door having a hole 3 or 4 in. in diameter which is plugged with fireclay during the working of the heat. Just before tapping, the fireclay is removed, the hole filled with old sacking slightly dampened. The furnace is tilted

in the usual way, by the time the sacking is burned through the slag line is above the tap hole.

The first helper tilts the furnace by a controller located just to the right of the ladle pit. The ladle is suspended so that the stream does not strike on the lining, nor on the sleeves and stopper rod, and is moved slightly to accommodate the shifting of the stream by the spout changing position in tilting.

When all of the metal and slag have drained completely from the furnace, four or five shovelfuls of lime are thrown on top of the slag in the ladle. This will act as an insulation and help to prevent too rapid chilling of the upper surface of the metal. The ladle is hoisted from the pit and taken to the pouring platform. If cold pouring is practiced—this is standard in the United States—the metal may be held quietly in the ladle for 5 to 10 min. until the temperature falls to the desired point. The ingots are then teemed.

Under no consideration, if quality steel is to be made, should any additions be made to the metal in the ladle¹ while tapping the heat. Recarburizing in the ladle, formerly practiced extensively in electric steel manufacture, is now discontinued in all shops. Except for one or two of the newer ferro-alloys used occasionally in electric steel; for example, ferrouanium and ferrozirconium which are added to steel with great difficulty, all additions can be made in the furnace where more time is available for their complete solution and distribution.

One of the most important things to remember in connection with the manufacture of good electric steel is: *Make the heat in the furnace, not in the ladle.*

¹ When ferrotitanium is used as a deoxidizer, it is usually added to the ladle.

CHAPTER VII

THE CHEMISTRY OF THE BASIC ELECTRIC PROCESS

The Oxidation Period—the Deoxidation Period—Factors Affecting Deoxidation

We have seen in the previous chapter that the basic electric process is divided into two major periods, very distinct chemically: oxidation and deoxidation. The first period, oxidation, is in many respects similar to basic open-hearth practice. The second period, deoxidation, is unique with the electric process. There is no other steel-making operation that accomplishes a thorough deoxidation by means of a reducing atmosphere and reducing slag. The acid open hearth approaches it more closely than any other process but even here, although oxidizing conditions may be controlled to some extent in the slag, the atmosphere in the furnace is, most of the time, sharply oxidizing.

In the oxidizing period in the basic electric process the scrap is melted or the hot metal is refined with oxygen introduced in solid form as iron ore, roll or forge scale or as rust on the scrap. By means of this oxygen, silicon, vanadium and phosphorus may be eliminated almost entirely; the other easily oxidizable elements, carbon, manganese, chrome, etc., are eliminated wholly or in part according to the conditions present, and the preference of the operator. In addition sulphur is removed to some extent.

It is obvious that when much oxygen is present in melting or early refining, the bath will contain more or less dissolved or entrapped oxides, principally ferrous oxide, which are harmful to the metal. It is the function of the deoxidizing slag to get rid of these dissolved or entrapped oxides completely. So, after the oxidizing slag is removed, as we have seen in the previous chapter, the white slag is applied to accomplish this final purification. The white slag performs three functions, all important and all very essential to a quality product:

(1) It contains strongly reducing substances, carbon and calcium carbide that will deoxidize any easily reducible oxides with which they come in contact.

(2) It forms a blanket over the metal, and prevents any contact between the surface of the metal and atmospheric oxygen. Any atmospheric oxygen that gains entrance into the furnace will come into contact with the reducing atmosphere or with the reducing substances in the slag, and thus will be rendered harmless before it can reach the bath of metal.

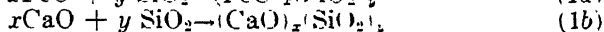
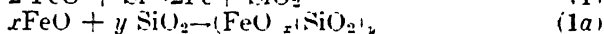
(3) It forms an active medium by which sulphur may be removed from the metal and retained permanently in the slag.

In the hot metal process to be described later, the oxidizing period is not present in the electric furnace,¹ the scrap or pig iron is melted and the oxidizable impurities removed in the open hearth. The electric furnace only performs the deoxidizing reactions.

THE OXIDATION PERIOD

Chemically the oxidation period may be divided into three distinct steps: (1) The elimination of the silicon and manganese, (2) the oxidation and removal of the phosphorus and (3) the oxidation of the carbon. If chromium and vanadium are present they are oxidized readily and pass into the slag as the oxides. It is not known definitely in just what manner, or just when in the oxidation period they are removed, probably the vanadium is among the first to go, chromium following about the same time as the manganese and acting similarly to the manganese, in that strongly oxidizing conditions are necessary for its complete oxidation.

The Elimination of the Silicon.—The first reactions taking place in the melting period² are:



The iron and calcium silicates immediately rise to the top to join the slag; the reactions are practically finished by the time melting is complete. It is probable that ferrous silicate $(\text{FeO})_x (\text{SiO}_2)_y$ forms in appreciable amounts early in the melting. This ferrous silicate is later broken up by substituting the stronger base CaO for the FeO. The ferrous oxide then migrates down into the metal and is actively concerned with the oxidation of the

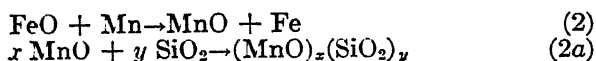
¹ This is true of the open-hearth electric process. If molten Bessemer metal is refined in the electric furnace oxidizing is necessary.

² Except a slight oxidation of the carbon which will be described later.

phosphorus and carbon. There is an appreciable amount of slag formed before melting is complete, and before much of the limestone has left the bottom of the furnace; although on account of the direct boring action of the electrodes in the first part of the melting period, there is always more lime present early in slag formation than in the basic open hearth.

The FeO present early in the period comes from the dissociation of any Fe_2O_3 or Fe_3O_4 present in the higher oxides in the charge as ore, scale or rust, although it is entirely possible that considerable early oxidation is accomplished by one of the higher oxides, Fe_3O_4 or possibly Fe_2O_3 .

The Elimination of the Manganese.—The manganese is oxidized in much the same manner as the silicon:



The manganese silicate immediately joins the slag and probably stays there permanently, at least more permanently than the ferrous silicate. The slag, therefore, at the end of melting will contain calcium silicate, manganese silicate, some ferrous silicate and possibly some free ferrous oxide together with the other constituents, calcium and magnesium compounds etc.

Theoretically silicon should be completely oxidized before manganese is removed at all. Actually some, perhaps considerable, manganese goes at about the same time although this reaction is never as complete as with silicon. It invariably lags behind silicon, which is completely eliminated at once, all but a trace being gone by the time melting is complete. Manganese can be partly controlled. Probably 60 per cent goes into the slag at about the same time as the silicon or a little later; the oxidation of the rest becomes increasingly difficult as the amount becomes smaller. As the amount of residual manganese decreases, more drastic oxidation must be employed to remove the balance. For that reason, it is easy to leave .10 per cent to .20 per cent in the bath but difficult to get rid of the final .10 per cent. A residual manganese of .10 per cent or below, especially below .05 per cent, is a certain indication that the bath is overoxidized.

As the amount of manganese in the charge increases, the chances of a high residual manganese in the bath increase; thus when melted with complete oxidation and using iron oxide, the

carbon may be below .07 per cent and the manganese below .07 per cent; while melting with complete oxidation using manganese ore, the carbon may be below .07 per cent and the residual manganese between .20 and .35 per cent.

Unless a large excess of manganese is present in the charge, manganese ore for example, the oxidation of the manganese will take place before the carbon; so, if iron ore is used, or if the scrap is very rusty, a low carbon will be accompanied by a low manganese percentage.

To prevent excessive oxidation of the manganese, a condition desirable in many cases, we therefore have two alternatives:

(1) Melt with restricted oxidation of the carbon which will insure restricted oxidation of the manganese and leave from .15 to .30 per cent in the bath; or.

(2) Melt with a large excess of manganese in the form of manganese ore which will insure removal of the carbon but leave .15 to .30 per cent residual manganese in the bath.

We will have occasion to take up these two alternatives again in the next chapter where variations in melting practice are discussed.

Amount of Silica, Ferrous and Manganese Oxides in the First Slag.—The amount of silica, ferrous and manganese oxide¹ in the first or black slag varies in wide limits. Like the basic open hearth, and unlike the acid open hearth, the electric furnace black slag does not adjust itself to any definite composition. Silica will range from 10 to 20 per cent, ferrous oxide from 4 to 20 per cent and manganese oxide from 3 to 15 per cent. Table XII gives the chemical composition of three typical black slags. A is from a heat melted with complete oxidation, B is from a heat melted with complete oxidation using manganese ore and C is the first slag of a heat in which clean scrap was used and oxidation limited.

The principal advantage of an excess of manganese oxide in the slag is the fluidity conferred by the manganese silicates which have lower melting points than any other slag forming silicates. This may be of considerable moment in the basic open hearth but of little importance in the electric furnace. Fluidity in the electric furnace is more easily attained than in the basic open hearth; the slag temperatures are nearly always higher. Whereas it is desirable to have 10 to 12 per cent manganese oxide in the slag

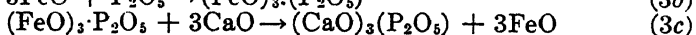
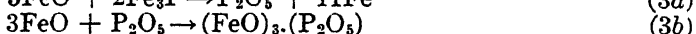
¹ In these pages, manganese oxide refers to manganous oxide, MnO .

of the basic open hearth, in the electric furnace, slags such as C, Table XII, are easily handled. If by any chance there is an excess of lime, as is the case with slag C, the slag may be quickly thinned by fluorspar.

TABLE XII.—COMPOSITION OF ELECTRIC FURNACE BLACK SLAGS

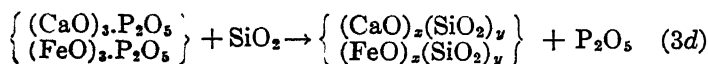
	A	B	C
SiO ₂	14.28	15.37	16.26
FeO	18.42	12.35	8.41
Al ₂ O ₃	2.07	1.96	2.84
MnO	8.43	12.65	4.37
CaO	43.17	44.31	53.23
MgO	12.47	11.65	13.78
P ₂ O ₅	1.09	1.76	0.82

The Oxidation and Removal of Phosphorus.—The removal of phosphorus depends for its completeness on three variables; (1) An excess of oxygen; (2) a very basic slag; and (3) a low temperature. The elimination of this element proceeds by the formation of phosphoric anhydride, ferrous phosphate and finally tri-calcium phosphate, reaction 3



Phosphoric anhydride (3a) formed by the reaction between the iron phosphide in the charge and the ferrous oxide is a very strong acid. It will immediately seize upon the most convenient base available, which of course, is the ferrous oxide dissolved in the metal, and will form ferrous phosphate (3b). Ferrous phosphate is not a permanent compound, it is easily dissociated and easily reduced. As soon as the ferrous phosphate reaches the slag, the calcium oxide, being a much stronger base than the ferrous oxide, replaces this compound to form tri-calcium phosphate (3c).

Phosphoric anhydride, P₂O₅, will be at once replaced by any free silica according to the reaction



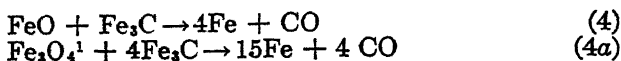
thus exposing the phosphoric anhydride to immediate reduction. For this reason, phosphorus cannot be eliminated as long as there is silicon left in the metal and free silica in the slag. It is through this ability of silica to replace the phosphoric anhydride in the calcium phosphate that phosphorus cannot be eliminated in an acid process by a slag high in silica. The slag must be high in bases, all of the silica combined, and there should be a large excess of lime, CaO , to replace the ferrous oxide in the unstable ferrous phosphate, forming the more stable tri-calcium phosphate.

The temperature has a most important influence on the rapid oxidation of the phosphorus. The oxidation of the phosphorus, silicon and manganese (chromium and vanadium as well) are all exothermic. The oxidation of carbon by reaction 4 is endothermic. Therefore below a critical temperature, which in this case is about 2,550 deg. F. (1,400 deg. C.), the oxidation of the silicon, manganese and phosphorus proceeds in the order named; the oxygen present after all of the silicon and most of the manganese are gone, oxidizing the phosphorus before the carbon.

Above this critical temperature sufficient external heat is being supplied to oxidize the carbon in preference to the phosphorus. As the heat is increased gradually in the cold scrap electric process, with ordinary care on the part of the melter, almost all of the phosphorus should have been removed before active oxidation of the carbon commences.

Oxidation of the Carbon.—This has been gone into in the previous paragraph where we have seen that a temperature above 2,550 deg. F. (1,400 deg. C.) is essential for the active oxidation of the carbon. There is, however, some oxidation of the carbon very early in the period, probably to some extent even before the scrap is melted. It is well known that steel may be decarburized to a considerable depth ($\frac{1}{8}$ to $\frac{3}{16}$ in.) at a bright red heat if an excess of oxygen is present. Although there is never as much excess oxygen present in the electric furnace as in the basic open hearth, it is certain that there is some carbon removal taking place at an early stage.

The bulk of the carbon elimination comes after the silicon, manganese, chrome and vanadium if present, and phosphorus have been oxidized and have gone into the slag. As we have already seen, the higher the temperature, the more rapidly this oxidation to carbon monoxide takes place, reaction 4 and 4a.



It is practically impossible to remove the carbon below .03 per cent and exceedingly difficult to get it below .05 per cent. Even when attempting to reduce this element below .06 or .07 per cent the oxidation of the bath becomes excessive. With normal practice, and with an excess of oxygen in the form of ore, scale, or rust, carbon removal will be constant and steady down to about .06 per cent. To attempt to get it much below this figure is increasing the possibility of inferior steel due to excessive oxidation.

To melt high in carbon, it is necessary to restrict the supply of oxygen by omitting ore or scale and by using a clean scrap. With only a small amount of oxide present, silicon will be oxidized and eliminated completely, likewise vanadium if present. The oxygen, by this time, will be practically all used up by these two elements, and consequently the oxidation of the chrome, manganese, phosphorus and carbon will be greatly restricted. By controlling the temperature, it is possible to remove some phosphorus in addition to silicon without disturbing the carbon greatly; also leaving a large percentage of the total manganese and considerable of the chrome in the metal. This is the basis of the practice of melting with partial oxidation and, as the foundation of first quality electric steel, is very important.

Elimination of the Sulphur in the Oxidizing Period.—There is some elimination of sulphur in the oxidizing period in the electric furnace. The exact procedure and amount oxidized is somewhat of a conjecture, but reactions involved can be fairly well established, and the amount eliminated set at about 20 per cent of the total. It is not of importance even to consider sulphur removal in the oxidizing period, as the white slag carried by the metal later removes this element rapidly and completely. As it does actually occur, we will consider it briefly.

Sulphur is always found to some extent, usually below .20 per cent in the oxidizing slag. The exact form in which it exists is a subject of some debate. The argument lies principally between the possibility of calcium sulphide and calcium sulphate. In the basic open hearth, sulphur may exist in the slag as calcium sulphate but in the first slag of the electric furnace containing

¹ Any Fe_3O_4 is reduced to Fe_3O_4 or FeO by the high temperature.

a much smaller excess of oxides than the corresponding slag in the open hearth, more sulphur as calcium sulphide should be dissolved. The sulphur exists in the steel as manganese sulphide. This constituent is insoluble in the molten bath, but is in such a finely dispersed or emulsified form, that but little will rise to the top. What little does escape from the bath, about 20 per cent on an average, is dissolved by the slag. Some of this manganese sulphide may burn to sulphur dioxide, SO_2 , and escape as a gas; the rest, probably the greater part, is held by the slag as MnS or CaS . The odor of SO_2 is occasionally noted just after the bath is melted, and sometimes distinctly when slagging off. Likewise, some sulphur is always detected in the slag by analysis.

Summary of the Chemistry of Oxidation.—Because in the control of oxidation often lies the final quality of the product, it is advisable, in order to emphasize duly the reactions involved, to summarize briefly the processes by which silicon, vanadium, manganese, chromium, phosphorus and carbon are oxidized and removed either wholly or in part from the molten bath during or immediately after melting. In order to have oxidation occur, the oxygen must be added in solid form; as no atmospheric oxygen is present except the small amount leaking in through the doors. The oxygen is added in the form of oxide, either as iron ore, manganese ore, roll or forge scale or rust on the scrap. The oxidation takes place in the following order:

(1) Silicon is all removed except a trace by the time melting is complete.

(2) Vanadium is all removed by the time melting is complete.

(3) Chromium, except in the case of the last traces, oxidizes easily and passes into the slag as chromic oxide. Unless a large excess of oxygen is present, there will be from .08 to .30 per cent left in the metal.

(4) Manganese oxidizes easily, but like chrome, as the residual amount in the steel become progressively less, the task of eliminating it becomes progressively greater. Its removal can be controlled by limiting the amount of oxide or by charging manganese ore.

(5) With the temperature below 2,500 to 2,550 deg. F. (1,375 to 1,400 deg. C.) phosphorus is readily oxidized to phosphoric anhydride, a strong acid which combines with ferrous oxide to form ferrous phosphate. The weak base, iron oxide, FeO , is

then replaced by calcium oxide, a strong base, to form tricalcium phosphate which is stable as long as there is a large excess of calcium oxide and no reducing substances in the slag.

(6) Above 2,550 deg. F. (1,400 deg. C.) carbon oxidizes readily and as long as there is sufficient oxygen will be removed from the bath down to a point close to .07 per cent. Removal of more than this, unless manganese ore is used, produces an overoxidized bath and often results in an inferior steel.

(7) About 20 per cent of the sulphur present is removed in the oxidizing period probably leaving the metal as manganese sulphide. Part of it is retained by the basic slag as this compound or as calcium sulphide, and part may be burned to sulphur dioxide, SO_2 . The removal of sulphur in the oxidizing period in the electric furnace is of little practical importance.

With the foregoing discussion, and the summary noted just above, we should be able to anticipate what will happen if the amount of oxide introduced during the oxidizing period is closely controlled.

(1) With an excess of iron oxide, silicon and vanadium will be eliminated to a trace, carbon, manganese and chrome eliminated to below .10 per cent, phosphorus to below .010 per cent and sulphur about one-fifth of the total. This is the basis of melting with complete oxidation.

(2) With a small amount of oxygen and the temperature controlled closely, silicon and vanadium will be almost completely eliminated, both will be below .03 per cent; phosphorus if not too high (not over .05, preferably not over .04 per cent) will be brought below .02 per cent. From 20 to 60 per cent of the total manganese, chrome and carbon will be oxidized and thus eliminated from the bath. Usually from 50 to 60 per cent of these three elements will be retained by the metal. This is the basis of melting with partial oxidation.

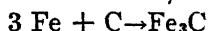
(3) With as little oxygen as possible; with clean scrap and no ore or other oxide used in the charge and when the slag is deoxidized as soon as the metal is melted—in other words, omitting the oxidizing slag altogether—silicon and vanadium will be almost completely eliminated, both will be below .05 to .08 per cent. Vanadium may be partly reduced from the oxide and go back in the steel. With silicon this reduction is negligible, most of it staying in the slag. Some carbon, manganese and chrome will be oxidized; the carbon is lost permanently, but the other two

elements are reduced from their oxides by the final slag and go back into the metal. Phosphorus is of course unaffected. This is the basis of melting without oxidation.

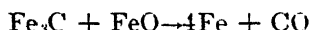
These three variations in oxidizing as here noted are important as they are the foundation for all basic electric furnace practice. They will be taken up again and in detail in the next chapter.

The Recarburizing Reactions.—The reactions taking place in recarburizing are not of especial importance, and as they have been discussed in part in the previous chapter, they will be touched on but briefly.

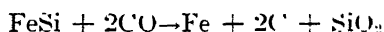
As recarburizing on the bare metal after the oxidizing slag is removed is nearly always with some form of carbon, this element combines with the iron as iron carbide,



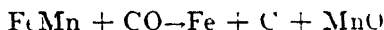
and as such is dissolved readily in the molten bath. All of the carbon added to the furnace does not go into the steel as iron carbide. If there is air in the furnace, some is burned to carbon monoxide, CO, and some is employed in reducing any ferrous oxide dissolved in the molten metal. This reaction causes,



when there is an excess of ferrous oxide, the boiling and wildness of the bath described in the previous chapter. Should this wildness become too prevalent at this time silicon is used for quieting,



which is accomplished very quickly. As we have already seen, some melters use manganese for this same purpose. The reaction here is



This latter reaction has the disadvantage that the manganese oxide formed is not permanent in the slag as is SiO_2 ; thus the work of the deoxidizing slag is increased.

THE DEOXIDATION PERIOD

As we have emphasized repeatedly, the deoxidation period is the important one in the electric process and is the foundation for the superior properties exhibited by electric steel. In Chapter VI, we have noted the method of building the white slag and have defined the two varieties of this slag, the white lime slag and the

carbide slag. We will now enlarge upon what we have learned and will view the two types of slag more in detail.

Types of Electric Furnace Deoxidizing Slags.—Although these have been previously described, it is essential that we repeat some of the details here. We have seen that the final slag is known as a white slag, principally from its light color from the high percentage of lime and absence of oxide, and to distinguish it from slags of other steel-making processes, and from the first slag of the electric furnace which varies from grayish black to brown or black in color and contains appreciable, sometimes large, amounts of ferrous and manganese oxides.

In present-day practice, white slags are of two general types; the white lime slag and the carbide slag. The first is composed of lime, coke and fluorspar or silica sand in a ratio approximately 12 to 1 to 2. The percentage of coke is so small that calcium carbide is usually absent altogether, or if present at all is contained in the slag in very small amounts and exists only around the electrodes. This slag was used almost universally a few years ago in electric furnace practice and is still common in a few plants.¹ It has few redeeming features and is not, as a rule, productive of high-grade steel. Its only justification, perhaps, is when very low carbon steel is made.

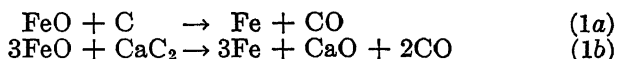
The carbide slag is the real deoxidizing medium of the electric furnace. This slag is also composed of lime, coke and fluorspar, very rarely silica sand; but in this case the proportion of coke to lime is very much increased. While the general tendency is to increase the percentage of carbide carried by the slag, the proportions of the ingredients may vary greatly depending on conditions in that particular shop and the preference of the melter. For an average composition 6 parts of lime to 2 parts of coke to 1 part of spar is about right. When a strongly reducing slag is required, the ratio may be increased to 3 parts of coke to 6 of lime. Again if less deoxidation is needed or if it is preferable to have a dead-melted bath, as is the case in making tool steel from washed metal and muck bar, 1 part of coke to 6 parts of lime is all that is necessary. The amount of spar as noted above is of course only approximate. As this is primarily

¹ In the past, melters seemed to have been afraid to use a large percentage of coke in the slag. Many of them have retained the fault to this day. This was probably due to their ignorance of the properties of carbide slags and to a fear that too much carbon would be absorbed by the bath.

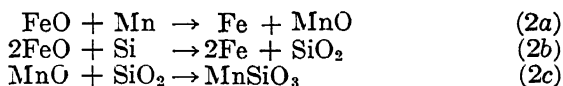
a thinning agent it follows that sufficient should be used to confer the fluidity desirable. The fluidity will depend upon the temperature of the bath and slag, the chemical composition of the lime, and the amount of contamination of the slag by small amounts of the bottom coming up. We may now look further at these two types of slag to see what their action is upon the bath.

Deoxidation with a White Lime Slag.—The white lime slag as originally added to the furnace contains 8 per cent or less carbon and is weakly deoxidizing. There is probably some calcium carbide formed around the arcs, but this is rapidly broken up by the oxygen in the air which leaks in through the door openings, before it can spread completely over the bath. Although as much as 8 per cent carbon may be added with the slag, very little remains, most of it burning to carbon monoxide as soon as it is thrown into the furnace. Only that reaching the center of the furnace around the electrodes where the atmosphere is always reducing remains to form small amounts of calcium carbide.

There is probably a small amount of reduction by the carbon or the carbide according to reaction (1)



In most cases it is negligible, the greater part of the deoxidation being accomplished by the solid agents ferromanganese and ferrosilicon, reaction (2),



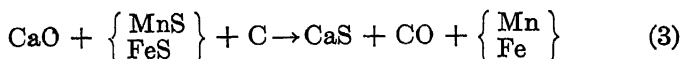
the manganese silicate formed readily leaving the metal.

Thus we see that while some deoxidation may take place according to reaction 1 above, the principal function of the slag here is to form a protective covering for the bath, not to act as a strong deoxidizing agent. If we must accomplish the bulk of the deoxidation by reaction (2), using ferromanganese and ferrosilicon, deoxidation in the electric process becomes very similar to deoxidation in the basic open hearth with the exception that in the electric furnace this deoxidation may take place in the furnace instead of in the ladle, as is necessary when the slag is oxidizing.

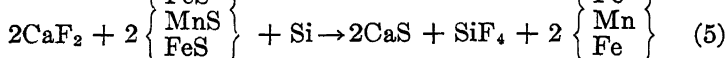
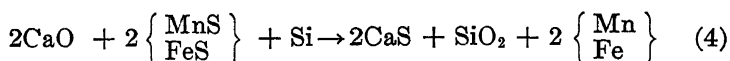
Desulphurization with a White Lime Slag.—The essential conditions for desulphurization are a strong basic slag and one

very reducing in character. From what we have learned of electric furnace final slags, it is quite evident that in this process the requirements for desulphurization may be completely met. We have a large excess of bases, the percentage ranging from 65 to 80, with 55 per cent to 65 per cent lime. We have a reducing atmosphere from coke added with the slag, from calcium carbide and from vaporized carbon around the electrodes. Thus desulphurization may become very complete in the electric furnace.

In the presence of a white lime slag assuming that calcium carbide is absent, desulphurization takes place in three ways, reactions (3), (4) and (5).



Reaction 3 is the most important of the three and probably accomplishes the bulk of the desulphurization.



It is not certain that reaction 4 accomplishes much desulphurization although it is certain that appreciable amounts of silicon which are reduced by the arc and by the carbon from the silica in the slag go into the metal.

It is probable that reaction 5 accomplishes more desulphurization than reaction 4 as fluorine is exceedingly active in the electric furnace. In any case, reaction 3 is predominant, reactions 4 and 5, if occurring at all, occupy a less important place in the elimination of this element.

After calcium sulphide is formed, it is very stable and is retained by the slag up to its saturation point. This point although not known definitely is between 4 and 5 per cent CaS. Because of the low percentage of sulphur (about 2 per cent), necessary to saturate the slag, it is important to keep the amount of this element in the slag making materials as low as possible. If, as occasionally happens, the lime contains .50 per cent., the coke 1 per cent and the spar .50 per cent the saturation point of the slag for calcium sulphide may be reached before all of the sulphur is removed from the steel. This makes it more difficult to desulphurize properly.

The saturation point of the slag for calcium sulphide increases as the temperature, fluidity and basicity increase. Thus we see that in the white slag we have five variables that effect desulphurization: (1) The amount of sulphur in the slag-making materials, (2) the amount of carbon or other reducing agents in the slag, (3) the temperature, (4) the amount of bases and, (5) the fluidity of the slag. The ideal slag for desulphurizing is one containing a high percentage of lime, and considerable carbon, maintained in a fluid condition and at a high temperature. It is important that the amount of sulphur in the lime, coke and spar be low.

The white lime slag contains a deficiency of carbon; thus its desulphurizing power is decreased. This has been proved in practice. Although the white lime slag will remove easily, and in most cases completely, .030 per cent or .040 per cent of the element, for higher percentages it is not nearly as efficient as the carbide slag.

The Advantages and Disadvantages of the White Lime Slag.—The white lime slag containing little or no calcium carbide has one advantage. Because of the small amount of carbon present, the bath will not increase in carbon by absorbing this element from the slag. Thus the white lime slag is used principally in making very low carbon steel.

The two disadvantages of the white lime slag are: (1) It is not strongly deoxidizing and (2) it is not strongly desulphurizing. Usually there is no justification for using a white lime slag unless very low carbon steel is made. Even then, a small percentage, .30 to .60 per cent calcium carbide may be carried by the slag without appreciable carbon absorption by the metal.

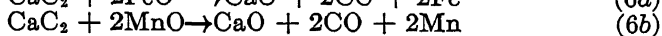
In appearance, the white lime slag may easily be distinguished from the carbide slag. Withdrawn from the furnace and poured into a pat on a clean iron plate, when but partly cool, it assumes a pure white color and falls rapidly apart or disintegrates into a fine white powder resembling burnt lime in appearance, but slightly coarser in texture. When the slag is pure white, it is usually an indication that ferrous or manganese oxide is not present in appreciable amounts. Although these two oxides are usually absent in more than traces (less than .50 per cent) this is not always the case. Sometimes the slag may be pure white and still contain more than 1 per cent of each. This is in contrast to the carbide slag where deoxidation is always positively accomplished.

General Features of the Carbide Slag.—The carbide slag, like the white lime slag, is strongly basic, containing as much as 60 to 65 per cent lime. It also contains .30 to 1.50 per cent carbon equivalent to .80 to 4 per cent calcium carbide. In color, the slag will vary from light to dark gray depending upon the percentage of carbon. Like the white lime slag, the carbide slag disintegrates into a fine powder on cooling. It usually takes somewhat longer for disintegration to start, than with the slag containing no carbide.

Carbide is readily detected by the strong odor of acetylene when the slag is moistened with water, although the odor does not give a definite indication of the amount present. After adding the slag to the bath, some 80 per cent or more of the coke thrown in will be rapidly ignited and burned away; if not at once, soon after it is in the furnace. The rest will remain entrapped in the slag as carbon or will form calcium carbide.

The carbon absorption by the bath is considerable, and varies with the method of mixing the slag before shoveling into the furnace, with the temperature of the metal, and with the time. In general, there is less absorption by the metal when the slag is built up in the furnace, as is common in the hot metal process described in a following chapter.¹ It is better to mix the slag thoroughly before adding to the furnace in the cold scrap process and allow for the carbon absorption, as this method of slag building produces a more rapid formation of carbide and, consequently, more rapid and thorough deoxidation. The carbon absorption from the slag can be made, with standardized practice, very constant; the average heat with the average carbide slag (Log Sheets 2 and 3) picking up one or two points (.01 to .02 per cent) of carbon per hour.

Deoxidation with a Carbide Slag.—Calcium carbide is a very strong deoxidizing agent. Consequently, the slag itself may accomplish the bulk of the deoxidation and leave little, if any, for the manganese and silicon. The deoxidation is accomplished by the reaction.



The reaction product carbon monoxide is gaseous and escapes; it cannot be absorbed and dissolved by the molten bath as the reaction is not in the bath, but at the contact of bath and slag.

¹ See also p. 127.

The first deoxidation accomplished by the calcium carbide is of the slag in which the ferrous oxide, manganese oxide or any other easily reducible oxides are reduced. When the slag is free or nearly free of oxides, the calcium carbide then attacks, by reaction 6, the oxides dissolved in the bath reducing these to the metal in three ways: (1) By the migration of the oxides from bath to slag to restore the disturbed equilibrium due to the slag being free from oxides, (2) at the point of contact between metal and slag and (3) through contact caused by the occasional stirring of the bath, when a new surface of metal is brought into contact with the slag.

If the amount of dissolved oxides in the metal is large, as happens when the heat is melted with complete oxidation, it may be necessary to make frequent additions of coke or coke and lime to replace the carbide destroyed by the excessive oxidation. When complete oxidation is used in melting, inferior and incompletely deoxidized steel sometimes results from the furnaceman not keeping the slag sufficiently strong in carbide from frequent coke additions. When the amount of dissolved oxides in the metal is large, the slag, if left to itself, will gradually lose its carbide through reaction 6 until none is left and the slag is pure white. Unless coke is added deoxidation then ceases.

Frequent opening of furnace doors for observation and other purposes is another cause of insufficient deoxidation. Every time a side door is opened, a strong current of air is drawn in by the up-draft of the hot furnace gases escaping out the roof between the electrodes and the cooling rings.¹ The carbide or the carbon in the slag may be acted upon by the oxygen in the air; the slag is then compelled to deoxidize the air as well as the steel, greatly decreasing the efficiency of the slag. It is, of course, necessary to open the doors for making additions, stirring the heat etc. Just before closing the door, it is a good plan to scatter a small shovelful of coke over the slag. This will immediately burn to carbon monoxide thus the carbide content may not be disturbed.

If deoxidation is accomplished thoroughly, the metal after being under a carbide slag for $1\frac{1}{2}$ to 2 hr. should show very little wildness. Although calcium carbide is not an efficient degasifier a fairly quiet metal shows that deoxidation is complete and degasification is being accomplished to some extent.

¹ This can be almost wholly prevented by the use of a suitable electrode economizer. See p. 70.

Degasification.—Silicon is the premier degasifying agent. The only objection to its use is that the reaction product, reaction 7,



is solid and tends to remain entrapped in the steel as an emulsified non-metallic inclusion. By deoxidizing on a very hot bath, some silicon is reduced from the silica in the slag by carbon (1,460 deg. C. is necessary for this reduction) and goes into the steel, reaction 8

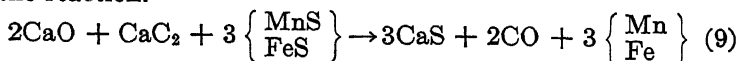


where it reacts instantly with any carbon monoxide encountered, reaction 7.

This action is going on sufficiently early in the heat so that the reaction product may have sufficient time allowed for its complete separation. The silicon reduced from silica in the slag is rarely sufficient to degasify completely. Consequently, ferrosilicon, 50 per cent, is added to complete the degasification. Because of the tendency of the reaction product to emulsify, it is advisable to make the addition of ferrosilicon in two or three portions adding part, at least an hour before tap, so the solid non-metallic inclusions will have time to rise to the top of the metal.

We have already, (p. 135) considered the method of taking heat tests to determine the temperature of the metal and the condition of the bath. A thoroughly deoxidized and degasified steel will lie quietly in the test mold with no sparking nor bulging of the upper surface, *i.e.* the exposed surface of the steel should be perfectly flat or slightly depressed. A steel not wholly deoxidized will bulge and rise up in the mold due to dissolved gases being thrown out of solution as the metal cools. A shower of sparks also indicates imperfect deoxidation and degasification.

Desulphurization with the Carbide Slag.—The carbide slag is the most efficient desulphurizing agent known. Provided the slag-making materials contain only a small amount of sulphur, the carbide slag will remove quickly and completely as much as .150 per cent, possibly more. Desulphurization takes place according to the reaction.



Perfect sulphur elimination is down to about .010 per cent. There is considerable doubt in the author's mind whether a removal much below this figure can be accomplished in the elec-

tric furnace. Although several instances have been published giving a final result of .005 per cent or below, in an experimental heat, three different carbide slags could not accomplish a total elimination. When the first carbide slag was removed, the sulphur was .012 per cent. After $1\frac{1}{2}$ hr. refining under the second slag, 3 points had been eliminated. The third carbide slag, after being on the metal for 2 hr., lowered the percentage to .008 per cent. It is not essential from a quality standpoint to remove sulphur to a point much below .020 per cent. But it is easily possible to eliminate it down to .015 per cent, in fact, this usually takes place in daily practice. The author, however, takes exception to several statements that this element may all be eliminated except a trace, (below .005 per cent).

In view of the difficulty of determining by chemical analysis the total sulphur in some electric steels, it is probable that in some cases where published results show a sulphur content of about .005 per cent, the true content was nearer .008 per cent or possibly .010 per cent. However, the whole question is of little importance; a sulphur content of .005 per cent to .010 per cent represents only .75 to 1.5 lb. of sulphur in 15,000 lb. of metal. Why worry about 1 lb. of sulphur, when several times that much foreign matter such as oxides and gases may be present?

Deoxidation versus Desulphurization.—One of the principal reasons why so much poor electric steel is made is because so many furnacemen lose sight of the real function of the white slag and think that the final period in the electric furnace is one of desulphurization. Sulphur is the only harmful element that the open-hearth melter cannot control; consequently, it is his bugbear and when he works on an electric furnace where conditions are ideal for desulphurization, he forgets all else. It is really surprising how many melters, yes how many superintendents, assume that the absence of sulphur in steel predicates the absence of oxides when this is only partly, never wholly, true. The sulphur may be very low and yet the steel will be blowy and unsound.

The white lime slag will desulphurize to a certain extent; if the original amount of sulphur is not over .030 or .040 per cent, it may be said that it will desulphurize completely. But it will not deoxidize, except superficially. The carbide slag will deoxidize completely and will desulphurize at the same time. In

fact, within certain limits, with the average carbide slag, desulphurization is practically automatic, and when deoxidation is complete, desulphurization is complete also. Therefore, we see that with the two types of electric furnace final slags, the white lime slag will desulphurize but will not deoxidize while the carbide slag will deoxidize and desulphurize.

Summary of the Chemistry of Deoxidation.—In the final or deoxidation period in the electric process, the function of the slag is to deoxidize the metal and eliminate sulphur. The steps involved are:

(1) Through the agency of carbon or calcium carbide, preferably by having an excess of the latter, any easily reducible oxides in the slag including manganese and ferrous oxide, also chromic oxide if chrome steel is made, are reduced to their various metals.

(2) As soon as the slag is free from oxides the deoxidation of the bath commences; any ferrous or manganese oxide in the bath being reduced to the metal through the agency of carbon or calcium carbide in the slag. This deoxidation takes place at the plane of contact between metal and slag either by migration of oxide from bath to slag, or through a change in the area of contact after stirring.

(3) By means of a very basic slag, a very fluid slag and the reducing properties of carbon or calcium carbide, sulphur is eliminated from the metal and held permanently in the slag as calcium sulphide.

(4) Deoxidation is assisted and degasification accomplished by the addition of ferromanganese early in the final period and by ferrosilicon just before tap or preferably in two or three doses at 20- to 30-min. intervals in the last hour or hour and a half.

Thus we see that we have in the deoxidation period, conditions present that are impossible in an oxidation process such as the Bessemer, basic open hearth or acid open hearth. The atmosphere in the furnace should be—and is when an excess of carbon is present in the slag—always reducing in character due to an excess of carbon monoxide gas. By means of this excess of carbon monoxide gas, the slag itself may be kept reducing in character, especially so by frequent coke additions. If the furnace atmosphere is reducing and the slag reducing it follows that the reducing conditions will affect the metal bath; and that since oxides are

absent from the slag in appreciable amounts they will, in time if not at once, be absent from the molten metal. A further result of these reducing conditions is the almost complete elimination of sulphur.

To secure the conditions essential for deoxidation, we have seen that the slag should be composed of lime and coke in the approximate ratio of 3 to 1, with sufficient fluorspar to confer upon it the desired fluidity. After the slag is brought into shape properly by the arc acting upon lime and coke, it is necessary to maintain this condition throughout the remainder of the heat by the addition of sufficient lime, coke and spar or combinations of the three, to retain the desired basicity, fluidity, and excess of calcium carbide.

After the slag has accomplished most of the deoxidation assisted early in the period by the addition of ferromanganese, ferro-silicon is added to degasify. This is readily accomplished, and if time is allowed and conditions are such that the non-metallic reaction products from the silicon addition will leave the bath, the steel will be very nearly free from solid non-metallic inclusions and free from occluded or absorbed gas.

FACTORS AFFECTING DEOXIDATION

It has often been stated by furnacemen and is no doubt true, that the final 30 or 45 min. of the deoxidation period is the crucial time in the production of high-grade electric steel. Several factors influence the composition and character of the slag and, consequently, since the metal is directly dependent on the slag, affect the composition and character of the metal. Too often in practice, the melter has worked to adjust his slag to the proper composition and character, only to have it change entirely in the last 30 min. of the period, undoing all of his previous labor and requiring complete reworking at the expense of much time and trouble. In some cases the slag cannot be brought into good shape again; it is even necessary at times to remove the slag completely and build up a new one. In addition to the care necessary to preserve good slag conditions, it is essential that all of the additions to the metal are well distributed, and in the case of ferro-silicon, that the bath is not only degasified, but that the reaction products from this addition are removed from the metal as far as possible.

It is desirable that we view for a few minutes the factors that affect the composition and character of the slag and metal in this critical period of the heat.

Factors Affecting the Final Slag Condition.—There are four factors that affect the final slag condition; all are important and will be discussed briefly. The factor that influences the slag more than any other and that often changes its consistency and composition radically, is fluorine. The effect of this element on the carbide slag has been investigated only recently.¹ For that reason, we will take it up in detail. Fluorine affects the slag by increasing its fluidity and indirectly decreasing its basicity. It is, on a whole, not harmful; on the contrary it is beneficial. This has been discussed before.

The three other factors all work toward a slag condition that is bad; they partially, sometimes wholly, destroy the efficiency of the carbide slag in a very few minutes. The first one is the admittance of too much air into the furnace destroying the reducing atmosphere and thus the reducing character of the slag; the second is caused by overheating the roof and upper side walls, in which case the brick will melt and the acid material drip down onto the slag; and the third, one of the most common, is due to patches of the bottom coming up to contaminate a fluid slag with a refractory, high melting material and incidently introducing ferrous oxide into a slag free from this constituent.

Sand versus Fluorspar for the Carbide Slag.—In a number of plants silica sand is substituted for fluorspar as a thinning agent. For this purpose it is effective, forming various calcium silicates with low melting points. The only advantage in its use is cheapness and the reduction of corrosion of the upper side walls and roof of the furnace which occurs with fluorspar. Its principal disadvantage is that it is not nearly as effective as spar in desulphurization. Also, it decreases the basicity too much. An argument frequently heard from advocates of the silica sand white slag is that, when fluorspar is used, the slag will adjust itself to about 20 per cent silica anyway, so why not add this much in the form of silica sand to start with? This is only partly true. A typical slag made with silica sand will contain 20 to 25 per cent silica, SiO_2 , while a slag made with fluorspar will contain from 12 to 20 per cent of this compound, only occasionally getting over 20

¹ Investigation at the U. S. Naval Ordnance Plant, South Charleston, W. Va., 1921.

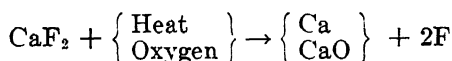
per cent. This is shown in Table XIII. Unless a large amount of spar is used, as is necessary with a high magnesian lime with the resulting severe corrosion of the roof, the slag should not contain more than 14 to 18 per cent. Since the spar is active in desulphurization while silica sand is not, this alone is sufficient to make it desirable to use spar instead of the cheaper sand even at the expense of roof corrosion. Also, it is doubtful whether corrosion of the refractories results in their earlier failure.¹

Sand also seems to interfere with the maintenance of a strongly carbide slag. In just what way this interference takes place, the author is not prepared to say but he has the word of numerous furnacemen who have told him that calcium carbide is less permanent in the slag made with sand, than in the one made with spar. We will now look for a moment at the corrosion of the roof by fluorine.

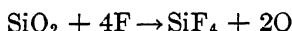
The Action of Fluorine in the Deoxidation Period.—Calcium fluoride is not retained permanently by the white slag, neither is it completely broken up and the fluorine volatilized which opinion is commonly held by most furnacemen. Its action is such that there is a continual breaking up of the spar, migration of the fluorine to the roof and upper walls, reaction with the silica in the roof brick, and final dropping back of the silicon tetrafluoride to the bath. The reaction of the fluorine may also be with any silica in the slag.

A recent investigation of fluorine in the electric furnace final slag was made at the U. S. Naval Ordnance plant. From the results of this investigation, the following reactions probably represent closely the chemical changes taking place in the slag due to the fluorine:

(1) The fluorspar breaks up by the action of oxygen or by heat alone²



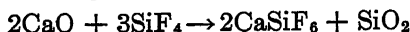
(2) The free fluorine attacks the silica in the brick of the roof or upper walls or even in the slag



¹ Lining and roof nearly always fail through cracking caused by uneven expansion and contraction. The corrosion of fluoroine is evenly distributed

² Especially in the vicinity of the arc.

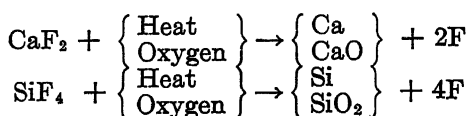
(3) Silicon tetrafluoride is formed in the slag or drips from the roof down into the slag where it reacts with the lime



(4) The calcium fluosilicate breaks up with heat



(5) Calcium fluoride and silicon tetrafluoride break up by the action of heat or by oxygen



(6) Fluorine attacks any silica, reaction 2, and repeats all through the final period steps 3, 4 and 5 depending upon the temperature, time and additions made to the slag.

These reactions may not be exactly correct; it is believed, though, that they represent very nearly what is taking place in the final slag. These reactions are based on the following facts:

(1) There is a continual corrosion of the roof. In a 30-ton furnace, it was calculated that the roof loses between 100 and 200 lb. per heat. Even with the worst furnace practice, and extreme overheating, this amount of brick could not possibly be melted away. Consequently, the loss must be accounted for by the reaction between the silica and fluorine.

(2) There are varying amounts of fluorine in the slag. Whether it is present as calcium fluoride or as calcium fluosilicate is not known, but analysis of final slags have shown that fluorine calculated to calcium fluoride will amount to as much as 35 per cent of the slag (Table XIII).

(3) Even when no sand is added to the slag, and when the lime, coke and spar are all low in silica the final slag will contain from 12 to 20 per cent silica, SiO_2 . (Log Sheet 2 and 3, pp. 174 and 182.) The large amount of silica can only be accounted for by the enrichment of the slag at the expense of the roof and upper walls.

(4) After an addition of fluorspar to the slag, the silica increases materially. (Log Sheet 2 and 3.)

(5) The continued presence of fluorine in the slag is shown by analysis. Totaling up the percentage of constituents in the slags noted in Log Sheet 2 and 3, the sum will fall considerably below 100 per cent. This is because the lime has been reported

as the oxide¹ when in truth it exists not only as the oxide (silicate) but also as either the fluoride or fluosilicate.

TABLE XIII.—ANALYSES OF ELECTRIC FURNACE WHITE SLAGS

	1	2	3	4	5	6	7	8
Silica, SiO ₂	15.32	17.48	5.50	12.70	19.54	13.20	22.58	18.40
Iron oxide, FeO	0.87	0.87	3.63	1.62	2.35	0.13	1.26	0.42
Alumina, Al ₂ O ₃	3.06	3.20	1.13	1.81	1.72	1.73	2.06	5.95
Manganese oxide, MnO	0.13	0.13	0.38	0.13	0.35	trace	0.37	0.45
Calcium oxide, CaO	57.63	45.02	38.64	50.86	51.63	75.85	63.87	61.26
Magnesium oxide, MgO	12.86	12.86	12.43	11.62	14.62	4.22	8.65	7.27
Calcium fluoride, CaF ₂	*	17.56	36.83	19.13	8.61	*	*	*
Calcium sulphide, CaS	1.69	1.69	1.07	1.71	1.05	1.22†	1.43	1.30†
Calcium carbide, CaC ₂	1.03	1.03	0.00	0.00	0.00	*	*	0.46
Uncombined carbon, C	0.22	0.22	0.33	0.15	0.09	*	*	*
Phosphorus, P	trace	trace	0.027	trace	0.008	0.039	0.009	*
Total	92.81	100.06	99.97	99.73	99.97	96.39	100.23	95.51

* Not determined. † Reported as sulphur, S.

No. 1. Analysis of a typical electric furnace carbide slag, approximate analysis. (From author's private notes.)

No. 2. Analysis of a typical electric furnace carbide slag; same slag as No. 1, exact analysis. (From author's private notes.)

No. 3. Analysis of an electric furnace final slag. This sample was taken early in the heat. The slag had been thick and viscous. A large amount of fluorspar was added, the sample was then taken as soon as the slag had thinned. (From author's private notes.)

No. 4. Same slag as No. 3 after 1 hr. Various additions of lime and coke have been made to the slag but no more spar. The slag was in good condition although not completely deoxidized when the sample was taken. (From author's private notes.)

No. 5. Same as Nos. 3 and 4 taken 1 hr. after No. 4. Various additions of slag-making materials have been added. Slag not in as good condition as in No. 4. Some of the bottom had come up just before the sample was taken making the slag thick and increasing the magnesium oxide and ferrous oxide content. (From author's private notes.)

No. 6. Final slag, 3-ton Girod furnace. (From LYON and KEENEY, *Electric Furnaces for Making Iron and Steel*, Bureau of Mines *Bulletin* No 67, p. 113.)

No. 7. Final slag made with sand, no fluorspar used. (From author's private notes.)

No. 8. Final slag, Heroult furnace refining hot metal, slag made of sand and spar. (From CAMP, "The Making, Shaping and Treating of Steel," Carnegie Steel Co., 1920.)

NOTE.—Samples No. 1 and 2 from 6-ton basic lined Heroult; samples 3, 4, 5 from 30-ton basic lined Heroult; sample No. 7 from 6-ton basic lined Heroult.

¹ The error in the regular analysis of electric furnace white slags is not only in the calculation of all of the calcium to the oxide but also in the silica. Any silica present as calcium silicate will be obtained by analysis by the regular method. Any silica existing in the slag as a fluosilicate will be volatilized and lost if the slag is analyzed by standard methods. It goes off as silicon tetrafluoride when acid is added to the slag or to an alkali fusion of the slag. The error in silica will be noted in slags 1 and 2 in Table XIII. This discrepancy in the silica results and the method of analyzing electric furnace white slags accurately was discussed in full in author's text, "Technical Analysis of Steel and Steel Works Materials," pp. 486 to 502, McGraw-Hill Book Co., New York, 1923.

Table XIII gives some analyses of electric furnace final slags taken at random from the author's notes and from various authorities. These various analyses show clearly the changing composition and the effect of fluorine in the electric furnace final slag.

The Influence of Atmospheric Oxygen on the Carbide Slag.—The second factor that influences the composition and character of the carbide slag is atmospheric oxygen. This factor is entirely preventable. The recent development and application of electrode economizers has served to prevent the chimney effect which causes a strong up-draft between the cooling rings and electrodes. Even when no economizer is used, sealing the furnace by luting the doors and other openings with fireclay and eliminating the very unnecessary frequent opening of doors will prevent the ingress of too much air. Likewise a small shovelful of coke scattered over the slag after opening a door is recommended. This carbon burning to carbon monoxide will eliminate any atmospheric oxygen.

The Influence of Overheating the Lining and Roof on the Carbide Slag.—Roof dripping due to overheating of the refractories can be wholly prevented by intelligent operation. It is never necessary to run the furnace so hot that the roof bricks melt and start to drip. During the early part of the deoxidation period, careful attention to the slag will avoid this overheating, even though the furnace is on high power. Overheating occurs almost wholly by reflection, therefore to prevent overheating, prevent reflection. A watery slag, smooth and mirror-like gives the maximum amount of reflection so early in deoxidation this should be avoided. The melter should aim to keep his slag fluffy and foamy without a smooth watery condition except just beneath the electrodes.¹ Should too much spar have been mixed with the first slag addition, lime may be thrown in the furnace or even a few small shovelfuls of crushed dolomite used to increase the viscosity.

When the furnace becomes so hot that the roof drips, the constant addition of molten silica to the upper surface of the slag completely prevents the formation of calcium carbide and will destroy any already formed. Oxidation is thus given full sway

¹ The intense heat directly underneath the electrodes keeps the slag very thin here. This condition can, however, be confined to a small area.

It is quite remarkable how quickly a dripping roof will affect the slag. In one instance, the combined ferrous and manganese oxide content increased from .61 per cent to 4.74 per cent in 12 min. This undesirable condition may be aggravated by pieces or even whole bricks falling into the slag from the roof and upper side walls. To cure the condition caused by a dripping roof, the power is reduced and lime is shoveled into the furnace. This is followed by an excess of coke. Finally fluorspar is added cautiously. The slag is thus built up anew.

The Influence of the Bottom Coming Up on the Carbide Slag.

When patches of the bottom come up, the melter is faced with a condition difficult to prevent and hard to cure. Of course, with a properly fritted bottom, little should work loose, but the fact that repairs must be made after each heat when 100 to 200 lb. of refractory are added, shows that about the same amount works loose and contaminates either the black or white slag. Most of the bottom that comes up, does so just after the bath is melted. Little contamination should be encountered in the final period. During deoxidation if any bottom at all works loose,¹ it will usually be in patches of considerable size. The patches of refractory contain sufficient ferrous oxide to destroy calcium carbide in the slag. When it is evident that some of the bottom is up, spar is added as necessary to thin the slag. The spar is then followed by an excess of coke.

All three of the above mentioned untoward incidents are likely to happen, and if immediate means are not taken to correct the bad slag conditions resulting, the steel will, in almost every case, be blowy, unsound and contain a harmful quantity of oxides.

Oring Down the Heat.—Sometimes, due to a mistake of the melter, through an error in the weight of the charge or wrong calculations and very rarely, because of a mistake made by the chemical laboratory, the carbon percentage when the last tests are analyzed will be too high.² In this case, unless the heat is diluted with muck bar, ingot iron or low carbon steel scrap, sufficient to reduce the carbon to a safe percentage, the bath must be ored down.

¹ That is in a normal 6-hr. heat. When a heat is in the furnace from 7 to 15 hr. as occasionally happens the bottom gets in bad shape.

² A high carbon percentage sometimes results from a piece of electrode breaking off and dropping down into the metal. Considerable carbon may be absorbed before the piece can be taken out of the furnace.

This is one of the most undesirable conditions that can possibly be present in basic electric furnace practice. The author has never seen nor ever heard, for that matter, of a heat 'ored down and then finished that was anything but poor in quality.

The procedure in oring down is somewhat as follows: The white slag is raked off and ore or roll scale added in small doses. The bath should be very hot so that according to selective oxidation a maximum amount of carbon will be oxidized in the shortest possible time. When the carbon has been reduced to the desired point, (100 lb. of roll scale will reduce the carbon about 10 points in 10 min.) the bath is stirred and a new white slag added. The slag and bath must then be completely deoxidized.

The process of oring down cannot produce anything but inferior steel because: In the first place, oring the carbon down after the heat is finished means that at least 2 usually 3 hr. additional are necessary. This extra time involves added wear on the bottom and lining, and nearly always results in large patches of the bottom coming up making it exceedingly difficult to keep the slag in shape. The ore added introduces an excess of ferrous oxide into the bath. Some probably remains unacted upon by the carbon and manganese. Some manganese and chrome, if present, are oxidized and go into the slag and must be reduced again, thus putting more work onto the slag.

Taking everything into consideration; when it so happens that the carbon percentage in the bath is too high and will result in an "off heat," it is far better and cheaper in the end to finish the heat and tap, trusting to the sales department to find a buyer for this higher carbon analysis. In fact, it is probably cheaper in the end to tap the heat and pour it as scrap than to work it 3 or 4 hr. longer in an attempt to get the analysis into the specified limit. It is probable that at least half the billets or bars will be rejected by the inspection department anyway.

Additional Deoxidizers.—We have had occasion to mention that aluminum and ferrotitanium are sometimes used as final deoxidizers. In addition to these common alloys, one or two others find use in a few shops. These are metallic magnesium, calcium silicide, and various alloys of manganese with silicon and titanium.

For aluminum little need be said. Although an efficient degasifier, its reaction product, alumina, Al_2O_3 , solid at bath tempera-

tures, tends to remain entrapped in the metal as an inclusion, making the cure as bad as the disease. Aluminum used judiciously causes no great harm; it might possibly, on the contrary do some good in degasifying a heat that could not be quieted any other way. In its efficiency as a degasifier lies the difficulty. Because a wild heat can be almost instantly quieted, to keep the metal easily available for the melter places before him a great temptation to slack up or slide over the laborious procedure of natural deoxidation and degasification and use aluminum to deoxidize and degasify all of his heats. Many a good melter has been spoiled by giving him an unrestricted supply of aluminum. The finest electric steel can be made without a stick of aluminum in the plant.¹

Ferrotitanium is another efficient scavenger. The same arguments applicable to aluminum apply to this alloy as well. Titanium is particularly effective in its ability to remove nitrogen. This ability is not of especial value in the electric process, as little if any nitrogen has access to the molten bath at any time during melting and refining. When used, 1 to 2 lb. for each ton are added to the metal in the ladle.

Calcium silicide is a new deoxidizer.² It is supposedly very efficient. It combines with oxygen forming calcium silicate which will rise to the top to join the slag. The reaction is extremely violent hence its use adds heat to the metal. On account of this violence, the alloy is added as a powder in small packages to the molten stream as it runs into the ladle.³ Ten to 20 oz. per ton are used for low carbon steels, 30 per ton for .30 to .50 carbon steels. The general results have been an increase in tensile strength of 5,000 to 7,000 lb. per square inch, an increase in elastic limit of 3,000 to 4,000 lb. per square inch and an appreciable increase of both elongation and reduction in area. These increased physical properties are, no doubt, due to the increased soundness. Two grades of the alloy are furnished, one has 24 to 28 per cent calcium and 65 to 70 per cent silicon, and the other has 18 to 22 per cent calcium, and 55 to 60 per cent silicon.

Final Resting before Tapping.—As we have noted in a previous chapter, it is customary in a number of plants to deoxidize on

¹ This statement applies to ingot producing plants.

² ANDERSON, W. S., "Calcium Silicide—A New Deoxidizing Agent," *Raw Material*, 4, 51-52, 1921.

³ This probably applies to open-hearth or Bessemer steel.

a hot bath; and after deoxidation is complete, to seal the furnace and turn off the power, letting the heat lie quietly until the metal drops to tapping temperature. This 5 to 20 min. resting is advantageous for a removal of the non-metallic reaction products left in the metal at the end of the heat.

We may assume that at the end of the refining period, after all of the alloys are in; that there is a dead-melted condition; that metal and slag are in equilibrium and that all alloys have dissolved completely or dispersed to a very high degree. In other words we may consider the bath to be a liquid colloidal solution in which iron is the solvent and in which are dissolved certain alloys and in which are suspended other alloys and small amounts of non-metallic inclusions.

A period of quiet will not decrease the degree of dispersion of the alloys but will decrease the dispersion of the non-metallic impurities tending to promote their coalescence into particles of sufficient size so they will rise to the top by gravity.

Either of two things should be done; either the non-metallic impurities should be dispersed into such a completely emulsified condition that sizable slag areas in the ingot will be impossible, or time should be allowed for the impurities to coalesce and thus leave the steel.

In the case of manganese and ferrous oxide, if there is a possibility of these two constituents being present, it is essential that time be allowed for their silicates to form and thus leave the steel. With solid silica, and with manganese sulphide, it is probable that if these two constituents are in an emulsified form they will, if present in small amounts, be harmless.

The final resting or dead-melted condition is therefore advantageous in that it will allow coalescing of non-metallic impurities, thus promoting freedom from these defects, but it is disadvantageous in that any solid non-metallic inclusions, uncombined silica for example, will tend to collect into slightly larger masses and not disperse into a desirable emulsified form.

The reader should understand that the condition above outlined discusses non-metallic inclusions that are present in very small, we might say infinitesimal amounts, so small that they may, except in the case of the highest grade steels, be almost negligible. In good furnace practice, by the time this final resting period is reached, the slag and bath should be practically free from manganese and ferrous oxide and that not removed

through the agency of the carbide slag, will be sought out by the solid reaction product, silica, which resulted from degasifying reactions, to form low melting silicates. It is the object of this resting period to allow these few silicates to coalesce and thus leave the steel. Even after the resting period, we will have present in the bath manganese sulphide, about 8 lb. to 15,000 lb. of metal; and silica, probably not more than 1 or 2 lb. per 15,000 of metal.¹ These two foreign constituents should be the only ones present in more than traces in the metal when ready to tap.

Convection Currents as an Aid to the Removal of Non-metallic Impurities.—The manufacturers of conducting hearth electric furnaces and some metallurgists, as well, have advanced the argument that convection currents are valuable aids to the final cleansing of the metal of non-metallic impurities. Others have claimed that a quiet dead-melted condition is more favorable. A positive statement either way is not permissible. This much may be said however; in the crucible process, the metal is dead-melted and killed to the point where it is absolutely quiet. And we all know the quality of crucible steel. This seems to be a strong argument in favor of dead-melting and final resting before tapping. But the argument should be tempered by the fact that in the crucible pot the body of metal is small, and in the electric furnace very large in comparison, therefore, though dead-melting may cleanse the metal thoroughly in the crucible pot it may not have the same effect in the 6-ton or 30-ton furnace. We do know this much positively, a final resting period in the direct arc furnace before tap is advantageous and produces a cleaner steel more free from non-metallic impurities than one that is tapped a few minutes after the final silicon addition.

It is claimed that convection currents, through a gentle movement of the bath, aid in coalescing low-melting point silicates. This is probably so. It is also true, however, that we rarely find silicate inclusions even at high magnifications, in steel from a bath that was given a final resting period of 5 to 15 or even 20 min. before tap and in which no convection currents were present.

Final Bath Condition before Tap.—We may with advantage summarize briefly: After deoxidation is complete and all alloy additions have been made we have in the furnace a hot metal covered by a very basic slag; this slag containing up to 65 per

¹ If the heat was melted with restricted oxidation the bath should be nearly free from silica; not over an ounce or two should be present.

cent calcium as calcium oxide with 1 to 3 per cent calcium carbide. The bath may be considered as a liquid colloidal solution with a large mass of iron as the solvent in which are dissolved various alloys such as iron and manganese carbides, nickel if present, etc., and in which are suspended in an emulsified form other compounds such as chrome carbides and very small amounts of foreign matter such as manganese sulphide, silica and possibly traces of iron and manganese oxides and the silicates of these two metals.

Through the agency of calcium carbide, FeO and MnO have been almost wholly eliminated from slag and bath, the addition of ferromanganese and ferrosilicon has, except for traces held through mass action, completed this elimination. So just before tap, these two oxides except for these traces may be considered absent. The fusible silicates of iron and manganese formed in small amounts have, by the final resting period, had time to leave the steel; so if this final dead-melting is carried out correctly, we may consider the bath to be free of fusible silicates, except for traces held by mass action.

Carbon monoxide gas has been eliminated by silicon leaving in its stead solid silica of which an excess, very small, it is true, but present just the same, remains dispersed in the metal. This foreign constituent, coalesces slowly and with difficulty so remains finely divided and thus, when so dispersed, is considered less harmful. Of this impurity, we may say that it is present not exceeding one part in 10,000.

Sulphur, of which about 3 lb. in 15,000 are present, is in the form of manganese sulphide. This inclusion is the greatest in amount of any at the end of the process. It is practically impossible to get it out of the steel and difficult to get it dispersed into a finely divided state. For that reason, manganese sulphide may be present in areas of appreciable size¹ in the finished steel.

The gases oxygen, nitrogen and hydrogen, because of the character of the charge and the method of introducing the heat, should be absent.

Thus we see, that except for 6 to 8 lb. of manganese sulphide and about 1 lb. of silica, the metal should be free from non-metallic inclusions. The most harmful inclusions, ferrous oxide and ferrous and manganese silicates so prevalent in basic open-hearth and Bessemer steel should be, except for minute traces, entirely absent.

¹ By appreciable size we mean visible at a magnification of 100 diameters.

CHAPTER VIII

THE COLD SCRAP PROCESS—VARIATIONS IN MELTING PRACTICE

Melting with Complete Oxidation—Melting with Partial Oxidation—Melting without Oxidation

In the two foregoing chapters, we have outlined in a general way the operation of an electric furnace, the production of a heat of electric steel and have sketched, in some detail, the chemistry of the melting and refining periods. In the present chapter, we will take up the three methods of making a heat and will discuss the relative advantages and disadvantages of each, and the effect of the melting practice on the quality of the product.

As we will see in the following pages, the three common variations in furnace practice, melting with complete oxidation, melting with partial oxidation and melting without oxidation are essentially variations in the method of melting, that is, in the oxidizing period; in each case the function and chemical action of the final or white slag remains the same, to deoxidize the molten bath completely and thus deliver a product into the molds that will be free from oxidation defects, non-metallic impurities and gas. While the function of the white slag is the same, its efficiency varies greatly according to the state of oxidation existing in the metal at the end of melting. We have considered it advisable to dwell with some detail on each variation in practice even if this involves some repetition of facts already stated in the two previous chapters.

MELTING WITH COMPLETE OXIDATION

Melting with complete oxidation is the simplest and consequently the most favored practice but is not productive of the soundest steel. This practice more nearly duplicates, in principle and in chemical reactions, the basic open hearth with the added feature of deoxidation and desulphurization. Because of ease in manipulation and because it makes use of the cheapest possible

raw materials, this melting practice was the first used for the production of electric steel and is in use today in a number of the shops melting in electric furnaces. It has its advantages, it has its disadvantages too, and the latter are so predominant that with some steel makers the practice is now only used for low carbon steel, and even here it is often modified.

Charging and Melting.—In melting with complete oxidation, limestone and iron ore or roll scale are charged on the bottom of the furnace followed by the scrap. The theoretical amount of oxygen necessary to remove the oxidizable elements should not be greatly exceeded, so if the scrap is dirty and very rusty, the amount of ore or scale charged may be decreased or even eliminated entirely. This is a matter of experience as each heat may demand different treatment. Many furnacemen charge a small amount of ore, say 50 lb.¹ and then add more, if conditions warrant after the heat is melted.

The charge for this practice is made up of the cheaper grades of scrap, country mixed, turnings, etc. It is desirable, though not necessary, to keep the amount of phosphorus in the charge below .080 per cent. If it has been found by experience that the mixed scrap runs higher than this it is usually diluted with 10 to 30 per cent low phosphorus scrap. While the oxidizing slag can easily remove as much as .150 per cent phosphorus, it often happens, sometimes without apparent reason, that when the charge is melted the bath will contain as much as .025 to .040 per cent of this element. When this occurs, the slag must be doctored with lime and ore and many times removed altogether and a new oxidizing slag applied. It must be remembered that the oxygen added in the form of iron ore or roll scale is the only means of oxidizing all of the phosphorus, as the electric furnace, in contrast to the open hearth has no oxidizing gases present. In fact, due to volatilized carbon around the electrodes, the furnace atmosphere may, even in the oxidizing period, be slightly reducing.

In any case, to melt down high in phosphorus means a half hour to one hour delay. For this reason and to be sure that the phosphorus will be below .020 per cent, and preferably below .015 per cent the average percentage in the scrap should not exceed .070 or .080 per cent. The slight extra cost of the 1 to

¹ The quantities of ore and other materials charged refer to the amount for the average heat of 14,000 to 16,000 lb.

2 tons of better scrap will be more than compensated by the saving in time.

The charge in this practice is melted as rapidly as possible; the bath should be hot when the metal is slagged off, consequently the furnace is kept on full power right up to the moment of slagging. After melting is complete, the first preliminary test is taken out and sent to the laboratory for analysis. If the practice has been well standardized the melter will know the composition of his metal exactly without a laboratory check. In fact, in most cases, he takes out his test and immediately slags off the heat. The phosphorus result will be reported by the laboratory before he finishes, it is not too late then to put another black slag on the heat, if through some unforeseen incident the percentage of phosphorus is too high.

Log Sheet 2, giving the history of a heat of chisel steel melted with complete oxidation, shows clearly the composition of the bath after melting is complete. In this practice, all of the oxidizable elements except sulphur will be reduced to very low percentages; the carbon and manganese are usually below .10 per cent and the phosphorus is below .020, often below .015 per cent and sometimes below .010 per cent. Only a trace of silicon is left. If chrome scrap was used this element will probably be below .20 per cent. About 10 sometimes as much as 20 per cent of the sulphur is eliminated in melting. This is shown in Log Sheet 2.

Slagging and Recarburizing.—The bath is slagged exactly as described in Chapter VI; particular pains being taken that all of the slag is removed. The black slag has a tendency to stick or hang to the banks, especially at the back of the furnace. It is evident that should any of the oxidizing slag persist in the deoxidation period, all of the phosphoric anhydride, P_2O_5 , in the slag will be reduced and the phosphorus will go back into the metal.

If the specifications require that the steel be below .020 per cent phosphorus, it is essential that the percentage of this element be below .015 per cent before slagging off. One or two points from traces of the black slag left in the furnace can be assured. In addition, the ferro-alloys will introduce at least 2 or 3 points more. The average rephosphorization in a plain carbon heat between the removal of the black slag and tap will average 3 to 5 points consistently.

LOG SHEET 2.—LOG OF AN ELECTRIC

Furnace.		C	
Heat No.		2,107	
Time	Log	Additions, pounds	
3:05 a.m.	Previous heat tapped		
3:15 a.m.	Bottom repaired—dolomite		175
3:15 a.m.	Began charging—limestone		600
	Iron ore		40
	Scrap—country mixed		9,700
	Shell rounds		2,100
	Punchings and turnings		4,000
3:50 a.m.	All charged—power on		15,800
6:35 a.m.	All melted—first test taken		
6:40 a.m.	Started slagging		
6:55 a.m.	Black slag off—recarburized—electrodes		125
7:00 a.m.	Bath wild—added crushed ferro-silicon		27
7:10 a.m.	White slag on—lime		500
	coke		150
	spar		100
7:15 a.m.	Furnace on high power		
7:40 a.m.	Slag light brown—added coke†		25
	spar		25
8:00 a.m.	Slag white—added lime (3) coke (1)		100
8:10 a.m.	Slag partly carbide—added ferromanganese		65
8:30 a.m.	Slag strongly carbide—heat warm		
8:35 a.m.	Slag thin—added lime		50
	Added ferro-silicon (50 per cent)		25
8:45 a.m.	Slag strongly carbide—heat very hot		
	Added coke (1) spar (1)		30
9:05 a.m.	Slag strongly carbide—power reduced		
9:10 a.m.	Added ferro-silicon (50 per cent)		50
	Added lime (1) coke (1)		50
9:15 a.m.	Heat test—metal hot—power reduced		
9:20 a.m.	Slag OK—metal quiet—added lime		
9:25 a.m.	Ready to tap—power off		20
9:30 a.m.	Final heat test—temperature OK		
9:35 a.m.	Tapped		
9:50 a.m.	Ladle test		

* Analysis of charge and scrap estimated.

† Slag and metal tests taken just before additions were made.

If medium or high carbon steel is made recarburization with ground coke or electrodes on the bare bath is always necessary. The recarburizer is readily dissolved, 60 to 70 per cent absorption can be depended upon. A certain amount of wildness always results from recarburization on the bath. The dissolved oxides which are present in large amounts in the molten metal from the

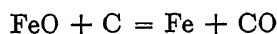
HEAT MELTED WITH COMPLETE OXIDATION

											C	Mn	Si	S	P
Analysis ordered.....											.65 .75	.25 .45	.15 .25	.020	.020
Metal tests					Slag tests										
C	Mn	Si	S	P	SiO ₂	FeO	Al ₂ O ₃	MnO	CaO	MgO	CaS	CaC ₂	P ₂ O ₅	P	
* .60	.60		.060	.090											
* .30	.30		.040	.040											
* .30	.30		.050	.060											
.07	.03	.008	.055	.075											
			.046	.015	18.37	19.22	3.17	7.05	40.31	9.43	.071 ¹		2.71		
.56	.05	.016	.040	.016	15.67	3.07	2.23	0.17	57.43	11.29	1.77	nil.		.014	
57	.04	.019	.035	.016	16.31	0.81	1.98	0.10	61.35	10.76	2.25	nil.		.003	
58	.04	.018	.031	.016	16.78	0.23	1.75	0.07	60.22	12.47	2.63	0.35		trace	
.61	.38	.023	.028	.017	21.26	0.17	2.02	0.04	56.13	13.17	2.91	1.26		trace	
62	.38	.087	.017	.017	17.33	0.13	2.21	0.13	58.14	13.53	3.17	1.73		.004	
63	.37	.093	.014	.018	19.17	0.09	1.98	trace	57.91	11.03	3.26	1.43		trace	
.65	.38	.228	.011	.018	20.20	0.08	1.97	0.03	57.29	13.41	3.56	1.58		nil.	
.66	.37	.207	.011	.019	19.36	0.09	1.78	0.02	56.41	12.87	3.43	1.31		nil.	
.68	.37	.214	.010	.019	20.28	0.05	2.13	0.04	55.31	14.38	3.48	1.21		nil	

¹ Reported as sulphur, S.

In this heat furnace doors open more than usual due to taking extra slag and metal test-

active oxidation in the first period react with the carbon which reduces them by the reaction



The large volumes of carbon monoxide gas given off produce the wildness and boiling characteristic of the metal at this point in

the practice. To quiet the metal either ferro-manganese or ferro-silicon may be used; we have seen in a previous chapter why ferro-silicon is preferred.

The amount of ground electrodes or coke added to the metal should be sufficient to bring the carbon content up to a point, so after alloys are added, the percentage resulting from the recarburizer and from the alloys will be two or three points below the minimum required. See Log Sheet 2.

After recarburizing and quieting the wild metal, the heat is deoxidized by a carbide slag.

Deoxidizing the Metal after Melting with Complete Oxidation.

It is necessary to carry a strong carbide slag after the metal is melted with complete oxidation. It is obvious that the more oxygen introduced into the metal in the first period, the larger the percentage of oxides dissolved and more work will be necessary to reduce the oxides and eliminate them completely.

The carbon added as recarburizer reduces a large proportion of the dissolved oxides but introduces, in their stead, a considerable amount of dissolved carbon monoxide gas, equally harmful and probably more difficult to remove than dissolved ferrous oxide.

After the slag is completely deoxidized, as shown by its color, and calcium carbide has formed in appreciable amounts, it is desirable to seal the furnace as tightly as possible to prevent the ingress of atmospheric oxygen. We have noted in the previous chapter that the slag will not be nearly as efficient if it must deoxidize the air in the furnace as well as the metal. Two or three thorough stirrings during the final period are sufficient to accelerate the deoxidizing reaction. From what we know of carbide slags and of oxide distribution in molten steel, 30 min. to 1½ hr. in contact with a slag containing an excess of carbide should be time enough to insure that the metal is free from oxides.

After about 1 hour's contact with the carbide slag, the metal may be deoxidized but still contains gases, especially when recarburized with carbon. The gases are in solution in such a finely dispersed form that the contact with calcium carbide is not sufficient to reduce them and thus eliminate them from the bath. Therefore ferrosilicon is used to degasify. As we have already noted, the reaction product from the reaction



is solid and tends to emulsify and remain in the steel, unless suffi-

ent iron and manganese oxides are present to combine with it, and form their respective silicates which rise easily to join the slag. The benefit of adding silicon, part of it at least, early in the deoxidation period is that, in all probability, some little iron and manganese oxide are left, thus the metal is rid of the last traces of these oxides, also, carbon monoxide gas is eliminated early, and the reaction product silica, has time allowed for it to coalesce, partly at least, and join the slag. All of the final addition of silicon should alloy with the steel if earlier deoxidation and degasification has been carried out completely.

At the end of the deoxidizing period, the metal should be nearly free from dissolved oxides and should be sound and gas free.

Making Low Carbon Steels.—Making very low carbon steels (.15 per cent carbon and under) in the electric furnace presents many difficulties as far as the final quality of the metal is concerned. The melting must be with complete oxidation as it is necessary to eliminate the carbon down to the lowest possible point. The carbon may all be removed except .06 or .07 per cent without oxidizing the bath excessively. Below this point, the metal may become overoxidized and almost impossible to put in good shape.

It is not advisable to have much carbide present or the metal may pick up too much carbon from the slag resulting in a final percentage that is too high. The bath, especially if very hot, will absorb carbon from a carbide slag or from a slag containing free carbon at the rate of approximately 1 or 2 points (.01 or .02 per cent) per hour. Under carefully regulated conditions, this increase of carbon becomes constant and is taken into consideration by the melter in calculating his recarburizer.

It is evident in making steel containing less than .15 per cent carbon, either the bath must be melted to a point below .07 per cent with danger of overoxidation or the slag must be kept low in carbon or carbide to keep the final carbon percentage below .15 per cent, (3 to 4 points are always introduced from the manganese addition; this is unavoidable). If the heat is melted too low and thus overoxidized, it is difficult to deoxidize thoroughly; if the amount of carbide in the slag is kept low, it is difficult to deoxidize thoroughly. The result is the same in both cases. For these reasons, it is difficult to make very high-grade low carbon steel in the electric furnace. It is because of these two difficulties, that many electric furnace plants produce seamy and unsound

low carbon case-hardening steel. In addition to these disadvantages, it is more difficult to desulphurize a low carbon heat than one higher in carbon.

The best results, in making low carbon steel, come from melting with complete oxidation but using manganese ore instead of iron ore or roll scale. In this melting practice, it is certain that there will be considerable, often as much as .30 per cent residual manganese in the bath when melting is complete. If the heat is melted with a manganese content of .30 per cent, a much smaller amount of ferromanganese need be added; the carbon from this source is only one point, rarely over .02 per cent, therefore, a much stronger carbide slag can be carried than if the heat was melted with iron ore. As manganese is a strong deoxidizer, it is evident that a large excess of oxides cannot be present in steel that contains much manganese. Therefore, residual manganese is beneficial in preventing overoxidation. From results in actual practice, it is positive that in melting with complete oxidation, unless the furnaceman is very expert in handling his carbide slag, the use of manganese ore as an oxidizing agent produces the best results, especially on low carbon steel.

The Advantages of Melting with Complete Oxidation.—Melting with complete oxidation has several advantages. In the first place, it is the simplest practice and demands the least attention on the part of the melter, that is, the least attention in oxidizing. After melting is complete the bath is of a definite composition, all of the oxidizable elements, except sulphur, have been eliminated down to definite small percentages. It follows, then, that this practice may be standardized and consequently handled successfully by comparatively untrained men.

Another advantage, perhaps the one that appeals to most steel makers, is that the cheapest scrap may be used. Opposed to this is the fact that all oxidizable alloys are lost. In the other two variations in the cold-scrap process the saving of alloys becomes, over a period of time, quite an item. The two advantages, namely, a standardized practice permitting comparatively inexperienced furnace labor to be used, and cheap raw materials, when combined, is such an important feature that some electric steel makers have retained the practice to this day. There is no doubt but that melting with complete oxidation produces cheap electric steel. We may also say that, in general, it does not produce the best electric steel.

The practice must be used on low carbon steels. When manganese ore is used, it is entirely possible to make sound steel even if all of the carbon is removed in melting.

The Disadvantages of Melting with Complete Oxidation.—The only disadvantage of this practice is that, as carried out in most shops, it produces an inferior steel. The two things productive of poor steel are the ease with which the heat is overoxidized and the difficulty of completely deoxidizing. Theoretically, the carbide slag should deoxidize no matter how badly the bath is contaminated, perhaps after the principles and reactions of deoxidation are better understood and more thoroughly put into practice, it will be possible to deoxidize an overoxidized bath completely; but now in the average shop, with the average melters, the more completely the bath is oxidized in melting, the more incompletely the steel is deoxidized with the white slag and the poorer the resulting product.

If melting with complete oxidation is necessary, it is productive of much better results if manganese ore is used for oxidizing instead of iron ore. Melting with complete oxidation, recarburizing on the bare metal, and the inefficient use of the carbide slag together with the silicon addition at the very end of the heat, is probably the cause of flake in electric nickel steel. For this one reason melting with complete oxidation should not be practiced with nickel steels, if possible to avoid it. For the low carbon case-hardening nickel steels it is, of course, very necessary to oxidize completely to get the carbon down. In this case silicon should be used early in the heat to reduce the possibility of flake. This well known defect will be discussed briefly in a later chapter.

MELTING WITH PARTIAL OXIDATION

In melting with partial oxidation, the supply of oxygen introduced into the furnace in the first period is sufficient to remove the silicon and a part of the phosphorus, manganese, carbon and chrome, if this latter element is present. If just a small amount of oxygen is present, silicon will be oxidized first followed by a part of the manganese, phosphorus next if the temperature is kept low, then a portion of the chrome and carbon. There is some carbon elimination throughout the latter part of the melting period. It is evident that a large amount of dissolved oxides cannot be present in the metal after melting is complete, consequently, the procedure of deoxidation is much simplified,

and from the postulate stated frequently that the more highly a bath of metal is oxidized, the more difficult to deoxidize and the poorer the steel, it follows that melting with partial oxidation produces a much better grade of steel than melting with complete oxidation. This has been proved in practice.

As this practice is productive of the best results in commercial electric steel manufacture,¹ and as it is applicable to all grades of steel except those containing less than .25 per cent carbon, it will be discussed in detail.

Charging and Melting.—The basis of melting with partial oxidation is to restrict the supply of oxygen as much as possible during the melting period. To this end, no iron ore nor roll scale is charged with the scrap. The condition of the scrap, too, is carefully watched so too much fine, dirty or rusty material will not be present.

The limestone to furnish the base for the oxidizing slag is charged directly onto the bottom of the furnace, about 500 to 700 lb. being used for the average 15,000-lb. heat. Heavy scrap, such as scrap electric ingots or ingot butts, is charged next, followed by the medium scrap which forms the bulk of the charge with this practice. Billet and bar crops, scrap ends of rails, boiler plate and other similar scrap are used for carbon steels; and gears, axles, forging scrap, etc., for alloy steels. A small amount of fine scrap is charged last.

As the only supply of oxygen comes from the rust and scale on the scrap, it is evident that this supply will never be large and that the amount of oxidizable elements removed will be small; therefore, it is necessary to keep the percentage of phosphorus which must be low in the finished steel, as low as possible in the charge. It has been found by experience that the slag conditions present will reduce a phosphorus content of .040 per cent or below to .015 per cent or below without difficulty. When the scrap contains more than .040 per cent, trouble is often encountered because the slag is deficient in oxides. Economically it is best, due to the slight difference in cost between guaranteed low phosphorus scrap and the ordinary mixed variety, to use for a charge, scrap that will average below .040 per cent and thus save the time and trouble encountered when the heat is melted too high in this element.

¹ Excepting the white slag melt-down which cannot be made a daily procedure on account of the lack of suitable scrap.

The charge is melted in the usual manner. When it is all molten except for the ring of pasty scrap around the banks, this scrap is pushed in as described in a previous chapter, p. 117. Pushing in hastens melting and, in addition, keeps the temperature low, thus facilitating phosphorus elimination. The composition of the bath after melting is shown in Log Sheet 3 which gives the history of a heat of .50 per cent carbon, chrome nickel air hardening steel for automotive work. It will be noted that all of the silicon has been eliminated and about half of the carbon, phosphorus and manganese. The chrome is in some cases hard to keep in the metal, in this case about 50 per cent has been oxidized.

The Condition of the Metal after Melting.—The oxidizing slag is removed exactly as detailed in Chapter VI. If there is much chrome in the charge, the oxidation of this element to chromic oxide, Cr_2O_3 , will tend to make the slag viscous and sticky. It is usually necessary to add fluorspar to the black slag to thin it enough to remove readily. The black slag in the partial oxidation process is inclined to be viscous even if chrome is not present, due to the deficiency of ferrous and manganese oxides.

It is never advisable, and very seldom necessary, to recarburize on the bath after the oxidizing slag is removed. Considerable residual carbon is left in the metal, and unless very high carbon steel is made, the melter usually adds his deoxidizing slag as soon as the black slag is removed, depending on the alloy additions and possibly washed metal or pig iron to bring the carbon up to the required limits. (Log Sheet 3.)

In making high carbon steel with partial oxidation, it is the practice in some plants to melt down high in carbon by charging pig iron, coke or other form of carbon with the scrap. If this is done, the carbonaceous material is charged with the first part of the scrap so it will be well down toward the bottom of the charge.

The Deoxidation Period.—Deoxidation is simpler when the charge is melted with a minimum amount of oxidation, because, as there are fewer oxides in the steel, it follows that it will be less work for the deoxidizing slag to eliminate these oxides completely. This has been found to be the case in practice. As a result, the time that the heat is under the white slag may, in many cases, be materially lessened without sacrificing the quality that comes from complete deoxidation.

LOG SHEET 3.—LOG OF AN ELECTRIC

Furnace.....		A					
Heat No.....		3,146					
Time	Log	Additions, pounds	Metals				
			C	Mn	Si	S	
1:10 p.m.	Previous heat tapped						
1:20 p.m.	Bottom repaired—magdolite	200					
1:20 p.m.	Started charging—limestone	750					
	Scrap—nickel chrome crops	7,400	*.30	.50	.200	.030	
	gears and miscellaneous	3,200	*			.030	
	scrap ingots	1,500	*.40	.60	.200	.020	
	low phos. scrap	2,200	*			.040	
	turnings	2,300	*			.050	
2:00 p.m.	Charging complete—power on	16,600	*.25	.45	.100	.034	
4:45 p.m.	All melted—first test taken—added spar†	30	.15	.26	.015	.030	
4:52 p.m.	Started slagging						
5:03 p.m.	Oxidizing slag off						
5:05 p.m.	White slag added—lime	550					
	coke	150					
	spar	100					
5:10 p.m.	Slag all on—furnace on high power						
5:35 p.m.	Slag nearly white—added lime (1) coke (1)†	50	.15	.23	.009	.024	
	Added nickel	210					
5:45 p.m.	Slag white, partly carbide—added coke†	25	.16	.25	.010	.020	
	spar	35					
	Added ferromanganese (80 per cent)	50					
5:55 p.m.	Slag carbide—heat hot—added lime	25	.19	.49	.016	.016	
	Added ferrochrome (68 per cent Cr., 6 per cent C)	285					
6:10 p.m.	Slag carbide—heat hot—added coke (1)						
	spar (1)	50	.30	.48	.023	.13	
	Added—ferrosilicon (50 per cent)	35					
	Added—washed metal	600					
6:25 p.m.	Heat stirred—bath warm		.44	.46	.088	.011	
	Added—nickel	50					
	Added—ferromanganese (80 per cent)	10					
6:45 p.m.	Metal hot—power reduced—slag OK		.46	.51	.081	.011	
6:50 p.m.	Heat test—added ferrosilicon	55					
7:00 p.m.	Bath stirred—power off		.47	.50	.231	.010	
	Final heat test—ready to tap						
7:05 p.m.	Tapped						
7:25 p.m.	Ladle test		.48	.40	.228	.010	

* Analysis of scrap and charge approximate.

† Slag and metal tests taken just before additions were made.

Log Sheet 3 shows in about what way the alloying additions are made. The melter should be on guard for a considerable increase in phosphorus in the deoxidation period. In the heat

HEAT MELTED WITH PARTIAL OXIDATION

Analysis ordered.....			C	Mn	Si	S	P	Ni	Cr				
			.45	.40	.15			3.25	1.30				
			.55	.60	.25	.025	.025	3.75	1.60				
tests			Slag tests										
P	Ni	Cr	SiO ₂	FeO	Al ₂ O ₃	MnO	CaO	MgO	CaS	CaC ₂	Cr ₂ O ₃	P ₂ O ₅	P
.030	3.00	1.00											
.030	2.50	0.50											
.015	2.00	1.00											
.040													
.060													
.035	2.00	0.60							†				
.014	2.07	0.28	13.47	8 31	2.26	5.08	50.35	10.61	0.093		8.37	1.36	
.015	2.05	0.22	14 07	2.26	1.97	1.08	56.37	14.55	1.63	nil.	0.43		.008
.015	3.31	0.27	15.86	0 46	2.17	0.17	61.09	13.69	1.77	0.15	0.17		trace
.017	3 29	0.26	18 32	0.17	2.06	0.21	57.13	12.81	1.93	1.06	0.06		.003
.019	3 23	1 45	17.06	0.27	2.37	0.06	59.36	13.17	2.03	1.01	0.04		trace
.020	3.18	1.43	18.29	0.16	2.09	0 03	57.11	14.04	2.17	1.21	trace		.003
.020	3.45	1.41	19.23	0.14	1.98	0.06	55.21	15.30	2.26	0.93	trace		.002
.021	3.44	1 40	20.17	0 14	1.86	0.05	54 03	14.37	2.17	0.76	trace		.002
.021	3 44	1.41	21 31	0.09	2.01	0.06	53.78	15.01	2 19	0.57	trace		trace

† Reported as sulphur, S.

In this heat, furnace doors open more than usual due to taking extra slag and metal tests.

illustrated in Log Sheet 3 the rephosphorization is about as follows: From traces of black slag 1 point, from the ferromanganese 2 points, from the ferrochrome 2 points and from the ferro-

silicon 1, possibly 2 points, making a total of 6 points (.006 per cent) in addition to that in the steel when oxidation was complete. As the sulphur is being eliminated constantly all during the deoxidation period, the amount of this element in the ferro-alloys does not, within reasonable limits, matter.

The heat shown in Log Sheet 3 is a typical example of recarburization by washed metal. This is the ideal way of adding carbon to the electric furnace. No other elements are introduced, this material containing carbon and iron alone, with only traces of impurities. With a hot bath, up to 1,000 lb. of washed metal, representing as much as 30 points of carbon (.30 per cent) with a 15,000 lb. charge, can be added safely at one time. With good furnace practice it should never be necessary to recarburize more than 25 or 30 points, even in a 1.20 carbon steel.

A form of adding carbon sometimes practiced in an emergency is electrode recarburization. The electrodes are run down until they extend some 5 or 6 in. into the bath. The absorption of carbon, by the metal eating away the electrodes, depends on the temperature of the bath. With average conditions, the bath will pick up a point (.01 per cent) a minute.

Advantages and Disadvantages of Melting with Partial Oxidation.—The principal advantage of this practice is that the quality of the steel is better than when the scrap is melted with complete oxidation. This is due to two things, first, a large excess of oxides is not incorporated into the metal in melting, and second, the oxidation of the carbon or the recarburization on the bath or both is not present to introduce a large quantity of carbon monoxide that must be removed later.

Another advantage is that the time of the heat, *i.e.*, the elapsed time from tap to tap is shorter with this practice than when complete oxidation is used. A fair average time in the latter practice is $6\frac{1}{2}$ to 7 hr., tap to tap. In partial oxidation, the final deoxidation period can be shortened so that the average elapsed time is 6 to $6\frac{1}{2}$ hr., often as little as $5\frac{1}{2}$ hr.

In this connection, there is no greater false economy than speeding up the heat, which is required in so many shops. Too much speed is the bane of all modern steel making and is especially harmful in the production of electric steel. The charging, melting and slagging cannot be greatly hurried, consequently it is in the deoxidation period that the temptation to

rush becomes great. So great is this temptation, that the author feels safe in asserting that 50 per cent of the electric steel made today is tapped before it is deoxidized and in 80 per cent of the manufacture of this grade of steel, if deoxidation is practically complete, degasification is accomplished in the ladle or not at all. The result is that often electric steel is far inferior to crucible steel, in fact it is only a fair, sometimes only a passable product. To make steel of a quality equal to crucible steel, the electric furnace must duplicate the crucible's dead-melt period and must allow the metal to lie quietly 10 to 20 min. in the furnace *after* deoxidation and degasification are complete. The only means of speeding up the cold scrap process is to speed up the deoxidation period by restricting the amount of oxidation, making the work of the white slag less difficult and thus shortening the time.

The principal disadvantage of the partial oxidation process is that the scrap charged must be of good quality and, consequently, is more costly than when melting with complete oxidation is practiced. It is probable that the average cost of the charge is \$3 to \$5 a ton more for the partial oxidation practice than the other. This extra cost is partly offset by the saving in alloys, a considerable proportion of the manganese and chrome, if these elements are present is left in the metal when melting is complete. The final alloy additions are thus materially lessened.

Another possible disadvantage is that care must be used in melting, especially in dephosphorizing, to remove this element completely without removing too much carbon and manganese. In other words, the practice of melting with partial oxidation demands skill and great care on the part of the furnaceman. When carried out correctly, it becomes the best procedure for making electric steel from a cold scrap base, that is, the most satisfactory method of accomplishing some refining, and yet producing a high-grade steel.

MELTING WITHOUT OXIDATION

The practice of melting without oxidation known in the mill as "melting under a white slag" or as a "white slag melt-down" consists, in brief, of melting a charge of high-grade clean scrap and deoxidizing the melted bath in the usual way. The black slag and oxidation period are absent. Melting under a white

slag duplicates almost exactly the crucible process as far as dead-melting is concerned. In addition, sulphur is removed. This is the only refining. Melting without oxidation may, therefore, properly be called a crucible process on a large scale. Accepting the statement made frequently, that the greater the amount of oxidation the harder to deoxidize and the poorer the resulting steel, it follows that melting under a white slag produces the best product possible with the electric furnace. With electric furnace operation as carried out in most plants, this has been the case. Although we take for granted that with present knowledge of deoxidation melting under a white slag produces the best steel, this method is not practiced widely, first, because suitable scrap is not available and second because many steel makers hesitate to depart from their present creed, "tonnage first, cost second and quality third." Supplementing this general discussion, we may now look at the white slag practice in detail.

Charging.—A small amount of limestone, say 50 lb.—many furnacemen use burnt lime advantageously instead—is charged on the bottom of the furnace followed by the scrap. As this practice does not remove any of the phosphorus and as a small amount is introduced by the alloy additions, the average percentage in the charge must be .005 per cent below the requirement in the finished steel. A specification of .020 per cent is very hard to meet with this practice as most of the scrap even from the electric steel plant's own mills or forges will range between .015 and .020 per cent. Buyers of electric steel are gradually being educated to the fact that steel with .025 or .030 per cent phosphorus is just as good as a material with .020 per cent and are allowing wider limits on this element. It is safe to use the white slag melt down if an upper limit of .025 or .030 per cent is permitted.

In this practice, scrap electric steel ingots, ingot butts, crop ends, and discards from the plant rolling mills, and scrap billets and bars are charged. It is difficult to secure small scrap of suitable analysis for this method of melting. In making alloy steels, the whole charge or 70 per cent at least may be scrap of the analysis required in the finished product, *i.e.*, for chrome steels, chrome scrap is used, (Log Sheet 4), for chrome vanadium steel, chrome vanadium scrap is used and for high speed steels, high speed scrap can be advantageously charged. In white slag melting, it is not advisable to overcharge the furnace, results in

this practice are better especially with some of the complex alloy steels melted in this way if the furnace is undercharged, that is 11,000 to 12,000 lb. in a 6-ton furnace instead of the customary 15,000 to 17,000 lb. After the charge is melted the metal is deoxidized in the usual manner.

Finishing the Heat.—As soon as there is a sizable pool of molten metal under the electrodes, the deoxidation of the slag begins. In melting without oxidation the slag must, in part at least, be built up in the furnace. This is different from the other two procedures where the slag is mixed on the floor before being charged into the furnace. To deoxidize the slag which, after the charge is nearly melted, consists of lime and oxides, two or three shovelfuls of coke are thrown into the furnace followed by a little fluorspar if necessary to thin. As melting progresses, lime, coke and spar are added until, soon after the scrap is entirely melted the slag should be in good shape, (Log Sheet 4), of the proper consistency, fluffy and white or nearly white. As soon as the slag is deoxidized as shown by the color, coke and lime are added under the arc, forming calcium carbide to deoxidize the steel.

In melting, all of the silicon is oxidized and goes into the slag permanently, some of the manganese, chrome and tungsten, if present, will also be oxidized and pass into the slag from which they are driven back into the metal upon deoxidizing the slag with coke. A variable small amount of carbon is oxidized and lost, about 10 per cent on an average, (Log Sheet 4).

A small portion of the vanadium, if present, is oxidized and will pass into the slag, all of it is not reduced back into the metal again. It is not known definitely what becomes of this small amount of oxidized vanadium but the fact remains, that melting down a charge of chrome vanadium scrap containing an average of .18 per cent of this element, the metal after deoxidizing will contain only from .13 to .15 per cent.

Log Sheet 4 shows clearly the chemical composition throughout a heat of carbon chromium ball bearing steel melted without oxidation. In this case, to prevent a too high carbon content after melting the ball steel scrap was diluted with some plain carbon scrap.

The heat is deoxidized and degasified in the regular way, by means of a slag containing an excess of calcium carbide for deoxidizing, and by adding the silicon in portions during the

LOG SHEET 4.—LOG OF AN ELECTRIC

Furnace.....		A				
Heat No.....		3,215				
Time	Log	Additions, pounds	Metal			
			C	Mn	Si	
5:50 p.m.	Previous heat tapped					
6:05 p.m.	Bottom repaired—magnolite	100				
	dolomite	150				
6:05 p.m.	Began charging—lime	60				
	Scrap—crop ends—chrome	7,400	*1.05	.38	.200	
	scrap bars	3,400	*1.05	.38	.200	
	scrap ingot butts	1,200	*0.95	.40	.200	
	carbon scrap	1,500	*0.65	.35	.150	
6:50 p.m.	All charged—power on	13,500	*1.00	.37	.190	
9:00 p.m.	Almost melted—added coke	25				
9:15 p.m.	All melted—furnace on high power					
	Added—lime	450				
	coke	100				
	spar	75				
9:45 p.m.	Slag white—partly carbide		0.91	.33	.023	
10:00 p.m.	Slag carbide—heat warm		0.92	.36	.020	
	Added lime (2) spar (1)	75				
10:15 p.m.	Slag carbide—heat hot		0.93	.36	.026	
	Added ferrochrome (87 per cent Cr., 6 per cent C)	60				
	Added washed metal	150				
10:30 p.m.	Heat stirred—bath hot		1.02	.35	.020	
	Added coke (1) spar (1)	30				
10:45 p.m.	First heat test—power reduced		1.03	.36	.031	
	Added ferrosilicon (50 per cent)	40				
	Added lime	30				
	coke (1) spar (1)	60				
11:00 p.m.	Second heat test—slag OK—metal quiet		1.04	.35	.107	
	Added ferrosilicon (50 per cent)	35				
11:05 p.m.	Power off					
11:15 p.m.	Metal quiet—slag OK		1.05	.36	.213	
11:20 p.m.	Final heat test—temperature OK					
11:25 p.m.	Heat tapped					
11:45 p.m.	Ladle test		1.06	.36	.207	

* Analysis of scrap and

In this heat, furnace doors open more than

white slag period to complete the degasification. Because there is no oxidizing slag to remove, and because the slag is partly deoxidized by the time melting is complete, the time of the heat with this practice is shorter than in either of the other two procedures previously described. The average time, tap to tap, is between 5 and 6 hr.

HEAT MELTED WITHOUT OXIDATION

								C	Mn	Si	S	P	Cr
Analysis ordered								1.00	.25	.15	.025	.025	1.35
								1.15	.45	.30			1.65
tests			Slag tests										
S	P	Cr	SiO ₂	FeO	Al ₂ O ₃	MnO	CaO	MgO	CaS	Cr ₂ O ₃	CaC ₂	P	
.015	.015	1.40											
.015	.015	1.40											
.010	.018	1.30											
.018	.016												
.015	.015	1.23											
.014	.016	1.18	13.73	2.07	1.67	.97	59.47	14.36	1.08	.95	0.27	.004	
.013	.016	1.22	17.68	0.53	1.81	.13	56.73	15.45	1.21	.09	0.86	trace	
.012	.017	1.21	15.57	0.23	1.90	.07	60.18	14.23	1.30	.08	1.06	trace	
.010	.018	1.50	17.31	0.06	2.03	trace	59.13	13.91	1.37	trace	0.93	trace	
.010	.018	1.49	19.26	0.09	1.97	.02	56.25	15.09	1.40	.06	0.67	trace	
.010	.019	1.48	21.37	0.13	1.76	.04	56.31	15.18	1.36	.06	0.71	.003	
.010	.020	1.50	20.67	0.16	1.81	trace	57.65	14.23	1.57	trace	1.03	trace	
.010	.020	1.49	20.86	0.09	1.78	trace	58.65	14.67	1.43	trace	0.86	trace	

charge approximate.
usual due to taking extra slag and metal tests.

The Advantages and Disadvantages of Melting without Oxidation.—The advantages and disadvantages of this practice have been touched on in the description of the process. It will only be necessary to summarize them briefly here. In a few words the advantages are; first, this method produces the best steel and second, if suitable scrap is available the steel may be

made quickly and cheaply. The practice is only adapted to the use of scrap from the electric plant's own rolling mills and forges; the purchase of a base guaranteed to be below .020 per cent phosphorus being practically impossible. The process is well adapted to the manufacture of high-speed steel as tungsten scrap may often be purchased in sizable lots, and much cheaper than if plain carbon scrap and the necessary amount of alloys were used; and to the production of alloy steels for which plenty of plant scrap of the same composition has accumulated.

That white slag melting produces a steel superior in quality to that made by either of the other two melting processes is unquestioned by any one familiar with electric steel. Its superiority is due, without doubt, to its freedom from oxides and gas which even with the best furnace practice seem to persist to a greater or less extent in electric steel in which oxidation was carried out to some extent. Even after an electric heat which was partly or wholly oxidized in melting is deoxidized to the best of the furnaceman's ability, degasified thoroughly with silicon and tapped, numerous small blue flames will be seen darting from the top of the slag in the ladle. These small pointed flames are carbon monoxide given off by the metal and burning to carbon dioxide in the air.¹ This condition is noticeably absent with steel melted under a white slag.

Turning to the question of the quality of the finished steel, the author had the opportunity to observe, over a considerable period, the inspection of tool steel bars (1 per cent carbon) made by all three melting processes. In every case the number of rejections for seams and other defects was much smaller, often only a half the rejections in the same grade when the heat was melted with partial oxidation, and usually only a fifth of the rejections necessary when melting was with complete oxidation.

The process, of course, permits of a saving of all of the alloys present in the scrap, and permits of much faster heats, as oxidation is absent and deoxidation is therefore much more rapidly accomplished.

Although we will discuss this again, we wish to make this one point: If the purchaser of electric steel would raise the limits of phosphorus, the scope of white slag melting would be greatly increased. There is an abundant supply of excellent scrap contain-

¹ These flames are also caused by the deoxidation by carbon of any FeO formed in the passage of the metal through the air in tapping.

ing less than .040 per cent phosphorus; there is even considerable containing less than .030 per cent; but when the requirement of this element is reduced to below .020 or .025 per cent the scrap available is very limited, so much so, as to make the practice only suitable for occasional heats.

The Best Furnace Practice in the Cold Scrap Process.—It may not be out of place to summarize the various steps that we have discussed in detail in the previous sections, emphasizing those steps that seem productive of the highest quality steels at a minimum cost. For emphasis, we will again repeat the postulate already formulated several times in the preceding paragraphs and use it as a basis for the summary. This postulate states: With present knowledge of electric steel manufacture, the farther oxidation is carried in melting, the more difficult and more incomplete is the resulting deoxidation, and the poorer the steel. Conversely, to permit very little oxidation to take place, simplifies and makes easier the final deoxidation and produces a higher grade product.

Using this statement as a basis, we may now sum up the process productive of the best results in the manufacture of basic electric steel from a cold scrap base:

- (1) Charge a low phosphorus scrap (.040 per cent or below) using as clean a material as possible.

- (2) Eliminate iron ore or other form of oxygen from the charge and melt low in temperature to facilitate complete removal of phosphorus, leaving in the bath when melted a portion of the carbon, manganese and any alloys present. An exception to this is in the manufacture of low carbon steels where manganese ore may be used for oxidation of the carbon without excessively oxidizing the metal.

- (3) Remove the oxidizing slag as completely as possible using lime to get rid of the final traces.

- (4) Do not recarburize on the bare bath after the oxidizing slag is removed. If very high carbon steel is to be made, use pig iron or other form of carbon in the charge, melting down so that the percentage of carbon when the oxidizing slag is removed will be high enough so that any recarburization may be made later with washed metal.

- (5) Mix the deoxidizing slag thoroughly before adding to the furnace. Use sufficient coke in the slag so that at least .50, preferably 1.00 per cent calcium carbide will be present all

through the deoxidation period. For the average heat, about 1 lb. of slag may be used for each 15 lb. of metal in the furnace.

(6) During deoxidation keep the furnace as near air tight as possible, only opening the doors for the necessary additions and an occasional stirring. After each addition, scatter a little coke over the slag to react with any atmospheric oxygen entering the furnace.

(7) Make all alloy additions, except vanadium, as early in the deoxidation period as possible, not, however, until the slag is known to be free from ferrous and manganese oxides.

(8) It is preferable to deoxidize on a very hot bath, as hot as possible without overheating the roof. Then towards the end of the deoxidation period, the power can be shut off completely, letting the metal lie quietly in the furnace until the bath cools to tapping temperature. This will facilitate the final removal of all non-metallic inclusions.

(9) Add ferro-silicon in two or three portions, at least 15 min. apart. This will promote early degasification, and will do much to eliminate trouble in the finished steel from seams and other surface defects.

(10) In tapping, hold the slag back so that slag and metal can not become mechanically intermixed in the ladle. It is best to tap a little too hot and hold the heat for 5, or possibly as much as 15 min. in the ladle before teeming the ingots.

CHAPTER IX

THE MANUFACTURE OF SPECIAL STEELS BY THE COLD SCRAP PROCESS

Melting Practice for Tungsten Steels—Melting Special Chrome and Chrome Vanadium Steels—Melting Special Nickel and Chrome Nickel Steels—Melting Carbon Tool Steel—The Manufacture of Fibrous Alloy Steels

In the last three chapters, the melting practice applicable to the usual variety of carbon and alloy steels has been noted in detail. Before leaving the cold scrap process and the manufacture of basic ingots, we will take up those few steels that demand special treatment in making, because of some special composition or because some inherent weakness in the finished product can be traced back to the melting and thus by proper care in this part of the process be eliminated, or at any rate closely controlled. As an example of the special composition, we may cite tungsten steel, particularly high speed, as one of the more complex products made by the electric process. As typical of the steels in which defects are common in the finished bar, a few of the chrome steels, especially the ball bearing varieties, and some of the chrome nickel steels including the high chrome, high nickel case-hardening variety may be mentioned.

Plain nickel steel causes much trouble to the maker because of a peculiar defect characteristic of this grade known as "flake." Flake is very prevalent in nickel steels whether they are made by the basic open-hearth or basic electric process; in fact this defect is a lot more common than the alloy steel makers will acknowledge. Although we do not care to enter into an extended discussion of flake, we will take the opportunity to cite an experiment made at a government plant which may throw some light on this hitherto unexplainable defect.

Because it is interesting as a possible competitor of the crucible process in the production of the very high-grade (so-called "extra special") tool steel, we will note briefly the wash metal, muck bar melting practice for the manufacture of this grade. This process, although practiced consistently by one plant for some time,

is not economically possible at present. Most purchasers of carbon tool steel refuse to pay the premium required for this grade by the higher cost of the base materials.

In this present chapter, the author wishes to note at some length the Austrian electric furnace practice for the production of the so-called fibrous alloy steels in which double oxidation is used and deoxidation is purposely but partly accomplished. This practice is noted here for what it is worth. It is directly against the viewpoint held by most American furnacemen that the more thoroughly deoxidized and sound the metal, and the more nearly it is free from inclusions, the better the resulting finished product. The reader should compare carefully the details of the fiber-producing practice with what has been stated in previous chapters concerning deoxidation. After this comparison, the relative advantages and disadvantages from a quality standpoint become readily apparent.

MELTING PRACTICE FOR TUNGSTEN STEELS

Up to the present time, only two grades of tungsten steels have been made; the tungsten finishing and magnet steels containing about 5 to 7 per cent of the element, no other alloys being present; and high-speed steels with more than 12 per cent tungsten together with chromium and vanadium, occasionally cobalt and uranium. Recently a class of chisel steels was put on the market containing tungsten, usually less than 3 per cent, with or without other alloys. In discussing the melting practice, we will confine our discussion to high-speed steels, the others present no problems not occurring in high-speed steel melting.

The Composition of High-speed Steel.—Two important varieties of high-speed steel are in common use.¹ They both contain between .55 and .85 per cent carbon usually between .65 and .75 per cent, although the tendency in the past few years has been to increase the carbon content slightly; many high-speed steels that are very successful in daily work having .75 to .85 per cent, even as much as .90 per cent. The manganese is kept as low as possible; always below .30, if possible under .20 per cent. Silicon is not so important; this element is, however,

¹ There are a large number of different compositions used for high-speed steel. The two varieties above mentioned are the two chief classes, *i.e.*, 18 per cent W and 1 per cent V, and 14 per cent W and 2 per cent V.

desired below .30 per cent, as many metallurgists consider that a higher content injures the hardening properties. Sulphur and phosphorus are, of course, desired as low as possible in the electric furnace product, the requirement is .030 per cent or below, sometimes as low as .025 per cent.

The difference between the two varieties of high-speed steel depends upon the tungsten and vanadium content. One variety is high tungsten, 16 to 18 per cent and low vanadium, .75 to 1.25 per cent; in the other the tungsten is 12 to 15 per cent with vanadium 1.75 to 2.25 per cent. In both cases the chrome is between 3.50 and 5.00 per cent. If cobalt or uranium is to be a constituent of high-speed steel, it is used in addition to the chrome, vanadium and tungsten; 3.50 to 5.00 per cent of the former and .50 to 1.50 per cent of the latter is the usual amount. They are not used to any extent as they have shown nothing remarkable. One authority says:¹ "The only notable recent development in high-speed steel composition was the addition of vanadium. Cobalt, uranium, cerium and zirconium have been tried but without benefit to justify their use."

The Melting Practice for High-speed Steel.—Furnace men always use as much high-speed scrap as possible in the heat, up to two-thirds or even three-fourths of the charge. There is nearly always high-speed scrap available and at a price that makes it a cheaper practice than if plain scrap and ferrotungsten are used. To save all of the alloys, melting must be without oxidation. After the bath is molten, and the slag deoxidized and free from tungsten, chrome and vanadium, a test is taken out and sent to the laboratory where carbon, manganese, chrome, vanadium and tungsten are determined. In most shops, a sample of slag is taken at the same time and analyzed for tungsten to make sure that all of this element has been reduced from its oxide and has gone back into the metal.

While the analysis is being made, (this will take from 45 min. to 1½ hr.) the slag is made carbide. As soon as the analysis results are received, the ferrotungsten and ferrochrome are added. Part of the ferrovanadium may also be added here, but it is considered better practice and safer to add this ferroalloy toward the end of the heat. As soon as the ferrotungsten and ferrochrome are melted, 20 min. is sufficient with a very hot bath, the heat is well stirred, and the final tests taken. These

¹ MATHEWS, J. A., *Proc. Am. Soc. Testing Materials*, 19, II, 141-181, 1919.

are drilled and sent to the laboratory where carbon, manganese, tungsten, chrome and vanadium are again determined. On this, the final analysis, chrome, tungsten and manganese should be within the required limits, the carbon very nearly up to the minimum and the vanadium content a little below that of the average in the scrap.

The ferrosilicon is now added, washed metal if necessary to bring up the carbon and the heat stirred. All of the ferrovanadium is now rapidly shoveled in and after 20 to 30 min., in which temperature is adjusted, the ladle is placed in position and the heat tapped.

Notes on the Melting Practice.—There is no need to hurry the melting and refining in high-speed steel making. The value of the charge for a 6-ton heat or even for a 3-ton heat is so great, that power and labor costs become very insignificant items in making this grade of material. High-speed steel while sometimes made in 6-ton furnaces is more often melted in lots of 1 to 3 tons. It is safer to handle this quantity than 6 tons. As high-speed steel is preferably poured into very small ingots, usually 3×3 or 4×4 , very seldom larger than 6×6 , it is evident that temperature in pouring becomes hard to control when 15 to 25 ingots are poured on a heat.

The carbon scrap used in the heat should be the best quality available; clean and free from rust and excessive scale. High-speed scrap is in a form suitable for electric furnace melting; it commonly consists of crop ends, scrap tools, etc, and is nearly always clean and free from rust. To dilute this good scrap with a poor material for the balance of the charge is poor economy. It increases greatly the oxidation in melting and the task of reducing the various metals from their oxides after the bath is melted. Again it should be emphasized that the cost of the alloys tungsten, vanadium and chrome is so excessive, and the final composition and uniformity so important, that the basic used and the time and power consumed become comparatively unimportant items.

Judging the temperature of high-speed steel, just previous to tapping, is very difficult. This metal pours differently; it is more viscous than the ordinary carbon and alloy steels. Likewise, the film test noted on p. 136 is apt to give erratic results as the metal films over more rapidly than carbon steel. In other words, high speed appears colder by the melter's usual tests than

other steels. Therefore, to the furnaceman inexperienced in high-speed steel melting the temperature may appear all right, but be much too hot. The correct tapping temperature is about 2,950 deg. F. (1,625 deg. C.). Allowing the metal to stand about 5 min. in the ladle will reduce this to 2,875 or 2,900 deg. F. which is about right for teeming. For a 3-ton heat, pouring 12 to 15 ingots, half 6×6 and half 4×4 , with this temperature will leave a bottom skull of about 100 lb. in the ladle. If the heat is 6 tons, at least 20 ingots must be poured. The metal should, therefore, be a little hotter, 2,950 to 3,000 deg. F. (1,625 to 1,650 deg. C.) when pouring is started.

Precautions in High-speed Steel Melting.—Although the electric furnace produces a high-speed steel equal, in some cases even superior, to the crucible in uniformity and chemical composition, one or two precautions are necessary so that uniformity will be attained. The first and most important is the tungsten addition. Two forms of tungsten are available, the ferro-alloy and the pure metal or powder. The ferro-alloy should always be used. Tungsten powder melts between 6,000 and 6,200 deg. F. (about 3,400 deg. C.). The average temperature of the bath in the final period is 3,000 to 3,200 deg. F. (1,650 to 1,760 deg. C.), not nearly high enough to effect quick solution of the powder. The ferro-alloy on the other hand melts between 3,500 and 3,700 deg. F. (1,925 and 2,040 deg. C.) which makes its solution in the molten bath very much easier. In addition, and this is most important, ferro-tungsten has a much lower specific gravity than the powder. Therefore, it does not settle to the bottom of the bath as rapidly as the powder. This settling of the powder is especially bad in that it drags considerable chrome with it.

There is a temperature, just what this is is not known definitely, above which iron and tungsten are miscible in each other. Below this temperature the tungsten whether ferro-alloy or powder tends to settle and lie on the bottom of the furnace in a layer; so to obviate this condition as much as possible, the metal should be very hot at the time of the tungsten addition; the bath should be stirred frequently after the addition, especially after cooling down prior to tap; and the ferro-alloy, crushed to pea size, used in preference to the powder.

Even with all these precautions, the first heat of high-speed steel in a furnace should be watched closely, as some of the tungsten added will go into the bottom and stay there. This

loss will amount to 30 to 60 lb. of the alloy with a 6,000-lb. charge and as much as 100 lb. with a 10,000-lb. charge. After the bottom is saturated by the first heat, subsequent heats will show no tungsten loss. After a campaign of high-speed steel melting on a furnace, a plain carbon tool steel heat can be conveniently made on that furnace to wash the tungsten out of the bottom. The first heat will contain from .30 to .80 per cent tungsten, a second heat will show about half as much, and a third heat a trace. In all cases, particular care must be taken with the first high-speed heat on a furnace, to prevent it finishing too low in tungsten.

MELTING SPECIAL CHROME AND CHROME VANADIUM STEELS

Some grades of chrome steels, especially the high carbon, high chrome (1.00 per cent carbon, 1.50 per cent chrome) series known as the ball-bearing steels are exceedingly difficult to manufacture properly in the electric furnace. The chrome and iron form compound carbides and oxides, perhaps even silicides, of apparently no definite nor constant composition and which give rise to innumerable defects in the rolled billet or bar. The actual melting practice of the steel is not difficult and presents no particular problems as does the high-speed grade. But, it has been found that carefulness and skill exercised by the furnace crew in handling these steels is in a great measure responsible for the final quality of the product.

Melting Practice on Chrome Ball-bearing Steels.—The chrome ball-bearing steels are all high in carbon ranging from .95 per cent to 1.20 per cent usually from 1.00 to 1.15 per cent. The chrome percentage in the regular variety is 1.35 minimum and 1.65 maximum. Silicon and manganese are normal, .15 to .30 per cent for the former and .25 to .40 per cent for the latter. Sulphur and phosphorus are low.

The practice best suited for this grade is melting without oxidation. Here ball-bearing steel scrap can be used with practically no loss of chrome, and the resulting steel is of the best possible quality. As we have already seen, due to the non-existence of an ample supply of suitable scrap, this practice is limited to occasional heats. Increasing the permissible limits of phosphorus would allow the steel manufacturer to make wider use of this practice and thus produce better steel. Lacking the scrap for the white slag melt-down, the next best practice is melting

with partial oxidation, as described in the previous chapter. By melting to retain most of the carbon, manganese and chrome present in the scrap, over-oxidation is prevented, thus simplifying deoxidation and producing a better final product. In this grade of steel, melting with complete oxidation is never necessary, and should never be used. It will be found that, in nearly every case, an over-oxidized heat and seamy bars result.

Another important point in ball steel melting practice: The ferro-chrome should not be added until the slag is strongly carbide and thus free from appreciable amounts of ferrous oxide, and until the bath is likewise deoxidized and free from dissolved oxides. Chrome readily oxidizes and, when combined with ferrous oxide, is one of the most highly refractory and inert substances found in molten steel. It is almost impossible to reduce this compound oxide; it thus remains in the metal and gives rise to numerous defects in the ingot, billet and bar. It is because of this oxide of iron and chrome that oxidation should be restrained as much as possible in the oxidizing period and the ferro-alloy addition made under the conditions above outlined.

After the ferrochrome addition is melted, the heat should be well stirred and the strongest possible carbide slag carried for at least another hour. During this final period of deoxidation the ferrosilicon is added in two or three portions.

The high carbon (6 to 8 per cent) ferrochrome is always used; the 2 per cent carbon and the carbon-free varieties are too expensive, except for special purposes or in an emergency. There is nothing in the composition of the ferro-alloy that is apt to cause trouble in ball steel heats except possibly silicon. This element may be present in undesirable amounts in the high carbon alloy. Although not proved, it is very possible, in fact probable, that when high silicon is present, a chrome silicide (Cr_2Si_2) may be introduced into the bath and cause trouble. Phosphorus and sulphur in the alloy usually may be neglected; the former is taken into account only when very low phosphorus (.020 per cent or below) steels are made.

Notes on the Melting Practice.—It is poor economy to hurry the heat when chrome steel is made. Here is an illustration: One company made their ball steel in a 6-ton furnace in 5 hr. melting with complete oxidation, adding their ferro-chrome early and tapping as soon as possible. They were greatly troubled with seams in their finished bars. Instead of looking back to the

melting practice, the difficulty was partly overcome by rolling the ingots to 4- to 6-in. rounds, annealing and rough turning, then reheating and rolling to finished size. These were sold as hot-rolled bars and were free from surface seams as this defect had been removed in rough turning. It is probable that had more care and time been given to the melting practice, and an effort made to produce clean steel in this part of the process, the expensive rough-turning operation could have been entirely eliminated. In addition, there was no certainty that the finished product, as sold, was free from internal seams and hair lines; only the visible defects had been removed.

Trouble is often encountered when chrome scrap is melted in quantity due to the oxidizing slag being viscous and difficult to remove. If oxidation has been controlled so that not more than 6 per cent of chromium oxide (Cr_2O_3) is present in the slag, three or four shovelfuls of fluorspar should thin the slag sufficiently for easy removal. The stickiness caused by chrome is greatly enhanced by a lack of acids and oxides of iron and manganese in the slag. The first slag of the electric process is, as we have seen, sometimes sticky, because it is high in bases due to the excess of lime and particularly because of the small amount of refractory bottom that invariably comes up and contaminates it. For that reason, and to limit the amount of fluorspar necessary, it is advisable to use a high silica limestone, one containing 5 to 7 per cent, in chrome steel heats melted with partial oxidation.

Melting Chrome Vanadium Steels.—Most of the precautions noted in the manufacture of ball steel are applicable to chrome vanadium steels. This composition of this class is roughly manganese, .40 to .80 per cent, chrome .80 to 1.25 per cent, vanadium .15 per cent plus, and carbon, variable, .20 to .60 per cent. White slag melting makes the best chrome vanadium steel although approximately one-quarter of the vanadium is lost in melting. Here, like in ball steel, suitable scrap is not available. The other favored practice is a combination of melting with partial oxidation and melting with complete oxidation. If the carbon content in the finished steel is around .50 per cent no ore is used; but when low (.20 to .30 per cent), manganese ore is added to the charge to supply sufficient oxygen and prevent over-oxidation by leaving .20 to .40 per cent residual manganese in the bath.

Although vanadium is a very efficient deoxidizer, and although chrome vanadium steels are sounder, as a rule, than chrome and chrome nickel, even here the addition of chrome should be made to a thoroughly deoxidized bath and slag for, if the difficultly reducible chrome-iron oxide is formed, even the vanadium will not produce soundness and seamy steel will result. The final slag is made strongly reducing by an excess of carbide; the ferrochrome is then added, and deoxidation continued for at least an hour, during which time the ferrosilicon is added in two or three portions. After the heat is quiet, the ferro-vanadium is added and the temperature adjusted for tapping. By adding the vanadium after the silicon and into a thoroughly deoxidized and degasified bath, 100 per cent of the added vanadium should be found in the finished steel.

One precaution should be noted in making vanadium steels. The ferro-alloy may contain up to 15 per cent or even more silicon. Unless this is taken into the calculations, the heat will finish too high in this element. The carbon content of the ferro-vanadium can be ignored as it is about the same amount as is required in the finished steel and is therefore self-contained. The phosphorus in the alloy may introduce one, rarely two, points into the steel.

MELTING SPECIAL NICKEL AND CHROME NICKEL STEELS

Most of the nickel and chrome nickel steels are very common and so are familiar to all furnacemen. With the principal ones the practice has been well standardized and a fairly uniform product is the result. There are a few compositions, however, that offer difficulties in the way of producing a sound finished product. These we will take up briefly here. It is unfortunate that electric steel makers almost universally hide their failures in furnace practice but publish joyfully their successes. The literature on the difficulties in the manufacture of electric steel is exceedingly scant. The furnaceman hates to acknowledge he can not make a certain composition. In fact, he will not acknowledge it. In many cases, we would have to examine his scrap pile to learn the truth. Therefore, in the previous section and in this one we have not taken up the steels that the melter "swears by," only the ones that he "swears at."

For practically all nickel and chrome nickel steels, nickel scrap is used. Chrome nickel scrap may be used just as freely,

often it is cheaper; the melter, however, dislikes to use the latter because of the thick slag he has to contend with at the end of the oxidizing period. The amount of nickel scrap is adjusted so that the percentage after the bath is melted will be from 50 to 75 points (.50 to .75 per cent) below the requirement.

Melting Nickel Steels.—The medium carbon grades are not difficult to make and so will not be discussed. As the percentage of carbon decreases, the difficulty of producing sound steel increases until it reaches a maximum with the special automotive and airplane case-hardening stock, containing .07 to .15 per cent carbon and 4.75 to 5.25 per cent nickel. For all low carbon nickel steels, the scrap is melted with complete oxidation, preferably with manganese ore. The carbon, after melting, should be .08 per cent or below. A little carbon, perhaps one point, can be expected from the manganese addition which is usually necessary. A fairly strong carbide slag can be used as a maximum of four points may be picked up, and the carbon still kept in the limits. No carbon to speak of is introduced with the nickel.

Nickel steel, especially when containing 3 per cent or more nickel, is sluggish and viscous even when hot and, as a rule, lies quietly in the furnace even before degasification by silicon. This makes more frequent "shaking" or stirring needed than with plain carbon or other more active heats. As the metal is sluggish, like high-speed steel the temperature is hard to judge. The set test (film test) is usually not reliable unless the melter is capable of adapting it to the conditions prevailing. Most melters judge the temperature by pouring a spoonful, as described on p. 136, making the necessary allowance for the sluggishness of the steel according to their experience and the percentage of nickel present.

Defects in Nickel Steel from the Melting.—Nickel steel is notable in metallurgical circles for one defect, "flake," a coarse crystalline structure sometimes accompanied by a slag inclusion, sometimes not. It results in a metal having a tensile strength somewhat less than the normal steel and no ductility as measured by the elongation and reduction in area. It is not the intention of the author to discuss flake, to do so adequately would fill a chapter, if not a volume, and the chances are, no more would be known about the defect than before. Flake developed during the war; it probably developed long before that but was brought

to light about that time. It is not a sharply defined defect, in fact it became rather popular (not in the usual sense of the word, rather it became notorious) a few years ago for some steel makers to cover up their inherently bad furnace practice by exclaiming: "Well it's flaked, what can I do?" The defect was popular because it could not be explained.

This much is known definitely about flake. It is prevalent in nickel steel, especially when containing about 3.00 per cent of nickel. It is rarely found in small ingots such as are made by the crucible process. It is rare in acid nickel steel, but common in basic. It is influenced by pouring temperatures and may be restrained by cold pouring. Neither temperature control of pouring, nor special forging or other treatment can eliminate it entirely. Therefore, it must go back to the melting. Summing up, flake must be a defect originating in the melting furnace, when nickel is present in appreciable amounts, and when the steel is the result of a basic melting process. Of course there are many exceptions to this; the above statements are only generalities but probably cover the defect fairly well.

The following experiment made at the Naval Ordnance Plant; where, by the way, every possible variation in pouring and forging practice would not eliminate flake, is offered as a possible explanation. A particularly large flake was chipped out of a fracture. It was analyzed and found to contain in excess of 10 per cent nickel. The flake of course was very thin, probably less than $\frac{1}{1,000}$ in. in thickness, so that even with careful chipping some of the metal behind the flake contaminated it. Therefore, from this result, the flake must contain segregated nickel. This element does not segregate, not as the element, but how about nickel oxide? Nickel supposedly does not oxidize in a bath of molten metal. That is, nickel does not form an oxide like manganese or chrome that rises to the top as slag. It may, for all we know, form some kind of an oxide and remain dissolved in the bath to segregate later causing these spots of weakness. It is probable that silicon or some compound of silicon reduces this oxide to the metal; because, if not, why is flake so prevalent in basic steel where little or no silicon reduction takes place and so infrequent in acid steel where there is a continual reduction of silica to silicon all through the last 3 hr. of the heat? There was no opportunity, at the above mentioned plant, to test this theory by lining an electric furnace

with acid material for the production of large nickel steel ingots, so a theory it remains, and as such is presented in this form as a possible basis for further and more conclusive experimental work. It is, undoubtedly, a good plan to add ferrosilicon early in a heat of nickel steel, degasification is more easily accomplished, and flake may be by this method partially, if not wholly eliminated.

Melting Chrome Nickel Steels.—The common chrome nickel steels give no more trouble in melting than do the chrome and chrome vanadium. Some melters consider the high chrome (1.50 per cent) high nickel (3.50 per cent) air-hardening steels difficult because of the sluggishness of a bath containing 3.50 per cent of nickel. Chrome nickel steels are very apt to be seamy. This defect can be largely controlled in the melting practice. If the steel is to be low in carbon, melting with manganese ore in the charge is recommended, with the addition of the ferro-chrome after complete deoxidation. It is probably best to add all of the nickel as soon as the bath is completely melted and the analysis results received from the laboratory. High power is then used to promote carbide formation and rapid deoxidation and to superheat the bath previous to the chrome addition.

A chrome nickel composition that gives much trouble is the low carbon, high nickel, high chrome case-hardening steel; the so-called "Krupp Special" nicknamed before the war because Krupp was about the only steel maker that could produce a satisfactory quality. In 1917 and 1918 several plants in this country tried to make it in quantity. One of them labored and worried some time and finally resorted to rough turning to get rid of the seams. The steel contains .08 to .16 per cent carbon, .30 to .45 per cent manganese, 3.75 to 4.25 per cent nickel and 1.40 to 1.70 per cent chrome. Melting must, of course, be with complete oxidation to remove the carbon to the lowest possible point. A slag containing much excess carbide is prohibited, as the bath picks up from two to four points from the slag, often a little more if the heat is in the furnace longer than usual. Electric furnacemen admit that in making sound steel of this composition, they are faced with an almost insurmountable task.

To melt down to .05 per cent carbon with iron ore, use a white lime slag containing no carbide so the carbon pick-up will

not exceed more than a point or two; and use 2 per cent carbon ferro-chrome to finish about .14 per cent carbon is the cheapest method as far as electric furnace costs are concerned. However, it is necessary, with this practice, to allow about 50 per cent for scrap loss on inspection of the hot rolled bars. The best practice is to start with clean low carbon nickel scrap and melt with manganese ore. Use a fairly strong carbide slag to deoxidize and add the chrome in the form of the carbon-free ferro-alloy, preferably the one made by the Thermit process, adding it only after the slag is free from ferrous oxide. After $\frac{1}{2}$ hr., add half of the ferrosilicon and after an hour, add the rest. Just before tap, tie four sticks of aluminum on the end of an iron bar and insert rapidly down into the bath moving it from side to side until melted. Stir the bath well before tap. This is about the only necessity or justification for the use of aluminum in electric steel manufacture. Although much more costly, in this practice the end justifies the means and the best finished product results.

MELTING CARBON TOOL STEEL

Plain high carbon tool steel forms a large part of the total product of the electric furnace.¹ It is here that the basic process has produced more fine steel than in any other branch of the special steels industry. The .65 to 1.20 per cent carbon tool steel was formerly made almost exclusively by the crucible process and by a few acid open hearth plants having small furnaces and specializing in a high grade product. The carbon content varies from .65 to 1.40 per cent depending upon the use to which the steel is to be put; the most common range is .90 to 1.10 per cent, the slightly lower carbon, .65 to .85 is a close second, while orders for the higher carbon steels 1.20 and above are comparatively scarce.

No alloys are present with the possible exception of chrome. Some tool manufacturers specify from .20 to .60 per cent of this element. Nickel should be as low as possible, many buyers prohibit a percentage exceeding .20. The difficulty of manufacturing tool steel without nickel is increasing steadily. Already the average nickel content in steels melted from plain carbon selected scrap is close to .15 per cent and as the element cannot be removed, it must, consequently, increase as time goes on unless a

¹ That is, the ingot production.

new source of scrap, for example steel resulting from the conversion of pig iron as in the Bessemer process, becomes available for electric melting. The manufacture of nickel steel rails and structural material from nickel bearing pig iron has put this element into steels ordinarily considered free from it. The seriousness of the problem of keeping nickel out of tool steel is increasing each year.

Melting Practice for Carbon Tool Steel.—In no case should melting with complete oxidation be used. On the contrary, the heat is melted down as high in carbon as possible, even if pig iron must be charged with the scrap to bring up the percentage of this element. As soon as the heat is melted, the slag is removed, the white slag applied and deoxidized rapidly. Tests are then taken out and sent to the laboratory for analysis. The bath is heated up during the first part of the deoxidation period, and when the analysis results are received, if recarburization is necessary, washed metal is used. A hot bath will easily take up to 1,000 lb. This is equivalent to 25 to 30 points (.25 to .30 per cent) of carbon for a 14,000 lb. heat.

We have already discussed recarburization in the ladle and will for emphasis repeat it briefly here. To make good steel never recarburize in the ladle. No good ever results, and the product, in most cases, is seamy and dirty. It is often a temptation to discontinue the use of the more expensive washed metal or low phosphorus pig iron and add crushed electrodes in the ladle. Commencing ladle recarburization increases at once inspection department rejections, and also, invariably starts complaints from customers.

A satisfactory preparation for recarburization of tool steel heats is known as Carburite and is a material consisting of carbon and iron, about 48 per cent carbon and 28 per cent iron. It is available in the form of bricks. It has the great advantage that it does not increase the weight of the charge which must, of course, be taken into account when washed metal or pig iron is used, and does not chill the bath to any extent as does a material containing only a small amount of carbon. The bricks are heavy and sink at once into the metal where the carbon is promptly absorbed. The author has never used Carburite and so can say nothing concerning the relative cost compared with washed metal or pig iron.

Melting Practice for Special High-quality Tool Steel.—Working on the theory that the purest raw materials produce the

best electric steel, one plant made a very high-grade product by duplicating the crucible process. A charge consisting wholly of washed metal and muck bar was used. It was melted without oxidation, and any slight recarburization necessary after the manganese was added, was made by washed metal. By calculating that approximately 10 per cent of the carbon is lost in melting, the amount of washed metal may be adjusted so that the bath, when melted, contained the minimum requirement. For example: If a charge of 15,500 lb. is used and a specification of .95 to 1.05 per cent carbon desired, the relative proportion of the two base materials is 11,500 lb. of muck bar or a clean low carbon steel containing .10 to .12 per cent carbon and 4,000 lb. of washed metal. The carbon in the charge, after melting, should be .91 of which 140 lb. will come from the washed metal (3.50 per cent C.) and about 12 lb. from the muck bar. Allowing for 10 per cent loss of carbon the bath would contain 137 lb. or .90 to .92 carbon. Three points from the manganese addition and about four points from the slag would bring the final carbon up to .98 per cent.

With this practice, a much more costly base is used. This is partially offset by the saving in time as these heats can be made satisfactorily in 5 hr. The resulting steel is the best possible and is equal in every respect to the best carbon tool steel made by the crucible process. It is in fact a crucible steel because the conditions present in the crucible pot are duplicated in every respect in the electric furnace; a high-grade raw material is used and the metal is dead-melted or killed during the deoxidation period. The electric furnace has the advantage over the crucible in that 15,000 lb. are produced at one time instead of 100 lb.

This practice may be duplicated at less cost by using as part of the charge, high-grade carbon scrap from the plant's rolling mills or forges, such as crop ends, rejected bars, etc. At least one plant has built up an enviable reputation for carbon tool steel by using the muck bar, washed metal practice. One point in its favor is that no nickel will be present as both washed metal and muck bar are, ordinarily, free from this element.

THE MANUFACTURE OF FIBROUS ALLOY STEELS

The article recently published by Dr. E. Kothny¹ describing the Austrian practice for melting chrome nickel steel for airplane

¹ *Chem. Met. Eng.*, vol. 27, no. 21, pp. 1020-1024, Nov. 22, 1922.

shafts is, because of its radical departure from our own established furnace practice, worthy of attention. The charge is melted and refined with the idea in mind of producing a so-called fibrous structure, a structure that, according to this writer, is necessary to meet Austrian army specifications. We wish to call attention particularly to the underlying fallacy and wrong impression given by Dr. Kothny in his article, that fiber is conducive to superior properties and that it is necessary to meet rigid specifications. In the experiment ingots were cast in three ways: (1) Into a sand mold, (2) into a cast-iron mold preheated to 400 deg. C. (750 deg. F.) and (3) into a cast-iron mold just a little above atmospheric temperature (about 50 deg. C.). Because the sand mold practice is not used at all in America for the production of ingots, and because the properties exhibited by the steel so cast showed nothing exceptional, we will confine our discussion to the properties obtained from the steel poured into cast-iron molds. An interesting fact developed that is well worth noting. The ingot cast in the cold mold solidified in 13 min., the one in the heated mold in 15 min. The structure of each was apparently the same. Thus preheating the mold evidently has but little effect on the rate of solidification and on the resulting structure.

Furnace Practice for Producing Fibrous Alloy Steels.—Selected scrap of the best quality was melted under a strongly oxidizing slag which was removed when the bath was melted. A second oxidizing slag was then applied and the heat worked under this slag for the desired time. Dr. Kothny uses an excess of ore, *not mill scale*. He says:

After skimming the latter (the second oxidizing slag) the finishing slag is made up using 1 kg. ferromanganese per ton of steel to hasten the reactions and bring the latter white in a minimum of time.

Evidently the ferromanganese is used here on the bare bath after the oxidizing slag is removed. The statement above is somewhat obscure and we do not see how the ferromanganese could be used with the slag. It is possible though, that the slag was added to the bath and followed immediately by the alloy.

He goes on to say:

When it is white enough ferromanganese is added to eliminate red-shortness whereupon ferrochrome and ferrosilicon are added.

A metal sample is then taken and tested, and if this shows the bath to be all right, the temperature is adjusted and the

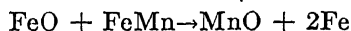
heat tapped. The treatment accorded to the metal test is somewhat unusual. A sample of sufficient size to pour a small 3-in. ingot in a chilled mold is removed from the bath.

This test ingot is forged to a slab 2 by 5 cm. (.8 by 2.0 in.) in cross-section. Two pieces 2 cm. (.8 in.) long are cut off and nicked longitudinally. Both pieces are hardened in water from 800 to 850 deg. C. (1,470 to 1,550 deg. F.) and one drawn back in a lead pot at 400 to 450 deg. C. (750 to 840 deg. F.). If the tempered piece shows a fibrous structure and good ability to flow, the heat is cast into forging ingots for making airplane shafts.

Discussion of the Melting Practice.—Let us analyze the melting practice to see what condition will be present when oxidizing is completed. In the first place a fallacy is at once apparent. The practice requires a *selected scrap of the best quality*. This predicates a clean, low phosphorus material. Very well. Now, Dr. Kothny charges an excess of ore with this selected scrap; he does not say how much, but probably about 40 lb. perhaps more for a heat of $2\frac{1}{2}$ tons; melts this charge, rakes off this slag, and adds *another* slag containing *more ore*. In other words, he introduces a large excess of FeO into the molten bath. In fact he probably saturates it. Now, if he saturates the bath with ferrous oxide, why cannot a rusty scrap be used? To use a clean scrap and then add an excess of iron oxide is contradictory to an extreme.

The metal at the end of the oxidizing period will, therefore, be nearly free from carbon, silicon, manganese and phosphorus and practically saturated with ferrous oxide. He admits this when he adds ferromanganese to eliminate red-shortness.

Discussion of Deoxidation.—In his account, Dr. Kothny makes no mention of any deoxidation by a carbide slag. He uses ferromanganese and ferrosilicon for this purpose. The first thing that happens is the reaction between the FeO and the ferromanganese.



This reaction is never 100 per cent complete although red-shortness is removed,¹ MnO replacing FeO. The bath, therefore, contains a little FeO and much MnO. On adding ferrosilicon he will have further deoxidation with the formation of iron and manganese silicates; probably a much greater amount

¹ Red-shortness caused by FeO is only apparent when a large excess of this constituent is present.

of MnSiO_3 than FeSiO_3 . The ferrochrome is then added and as soon as possible the heat is tapped.

Since there was little if any deoxidation of the metal by the white slag, and since the bath was greatly overoxidized, to be later deoxidized by manganese and silicon, it follows that at tap he will have a metal practically free from FeO and MnO but containing a large amount of suspended manganese silicate with possibly some iron silicate. Dr. Kothny closes his article by saying:

No difference in microstructure can be observed in heats which have a granular fracture and those which are fully fibrous.

This statement seems to be rather extreme but it shows that the suspended silicates which must be present are well dispersed to be invisible under ordinary magnifications.

From the description of the furnace practice the metal, at the moment of tap, is apparently almost free from FeO (because manganese and silicon are efficient deoxidizers) and MnO . However, it must be admitted that it will contain a large amount of manganese silicate and possibly some iron silicate. The reason for this is: Deoxidation was accomplished *in the metal* by solid deoxidizers and not *at the plane of contact* between metal and slag, as is the case in properly made electric steel deoxidized by the carbide slag. Although—this is important—the fusible silicates formed tend to coalesce and leave the metal, this cleansing is never complete when an appreciable amount of these silicates is present and thus the metal must, at the moment of tap, especially if tapping is hurried, contain an appreciable amount of these inclusions; whereas when electric steel is deoxidized by the carbide slag, thus removing the bulk of the FeO and MnO from the bath without the formation of silicates and only depending on the silicon to cleanse the bath of the final traces, it follows that the steel when tapped will be free from this class of inclusions.

The comparatively large amount of silicate inclusions present in the bath when overoxidized in melting and later deoxidized by manganese and silicon is, no doubt, the cause of the fibrous structure.

Further Treatment of the Fibrous Metal.—The ingots receive a reduction of from 65 to 80 per cent. The manganese silicate is thus worked down into fibres; mostly this working is in a longitudinal direction. It may, however, be to a slight degree in a

transverse direction, if the ingots are forged or hammered instead of being rolled. It is well recognized that manganese and iron silicates are harmful to steel because they break up the continuity and cohesion of the grains. In the case of rolled material, the non-metallic inclusions present will, of course, be elongated in the direction of hot-working and thus will have little if any influence on the cohesion of the grains in the longitudinal section, as their cross-section, if the reduction in rolling is high, will be infinitesimal.

Transversely, however, we have a different story to tell. These inclusions which are rolled into fibres of minute cross-section and which have practically no influence on the continuity of the grains, and thus on the physical properties of the longitudinal test piece, exert a very serious influence on a transverse section. Transversely, the cross-sections of these silicates are comparatively large; their effect upon the continuity and cohesion of the grains is great, therefore we find in every case that the physical properties of the transverse test suffer.

It is for this very reason that the United States Navy has practically eliminated the so-called fibrous armor plate which, by the way, is an adaptation from Germany, and has insisted for some years that the steel submitted to the government for ordnance purposes pass stringent transverse physical tests. The tests now required by the Navy are all transverse; basic open-hearth steel can pass them but seldom;¹ acid open-hearth steel does much better, but passes only when great care is used in deoxidation; but electric steel made right passes every time and in almost every case greatly exceeds the requirements.²

Fiber and the Transverse Physical Test.—Granting that the requirement of stringent transverse tests is necessary for good ordnance and other high grade steels, let us look at the effect of fiber on the transverse test. In the first place, the transverse test is a test cut from the metal at approximately right angles to the direction of hot working. In a forging for a gun tube, it is taken radially out from the center. Thus the transverse test in ordnance, or in any other high-duty steel for that matter, represents the direction of greatest strain. In big guns it surely does, as firing strains are exerted radially and thus transversely against the tube.

¹ See p. 16.

² Tests made on electric steel at the U. S. Naval Ordnance Plant.

When the stress is in the same direction as hot working, the fibrous steel holds its own very well. It is certainly not superior to clean steel but the bad influence of the silicate inclusions, in the case of the longitudinal test, is practically nil. This bad influence becomes greatest in the transverse test. No doubt, could we eliminate non-metallic inclusions altogether from steel, the transverse test would show physical properties almost as good as those of the longitudinal test. This is the case now with well-made electric steel. We are almost positive that the direction of hot working has but little actual influence on the physical properties of steel; it is the non-metallic inclusions which are always present and which become elongated and spread out when the metal is very plastic, that break up the continuity and cohesion of the metallic grains and thus afford points or even spots of weakness which lower the physical properties, which lowering is almost always evident in the transverse test.

Comparison of Physical Properties of Fibrous and Clean Steels.—It is interesting to note the specifications for airplane motor shafting for the Austrian army:

	Longitudinal test, lb. per sq. in.	Transverse test, lb. per sq. in.
Elastic limit, minimum	135,000	135,000
Ultimate strength, minimum	149,500	149,500
Elongation, minimum, per cent	7	4
Contraction, minimum, per cent	45	15
Notch toughness, kg.-m.	8	2.5

All fractures, and the nick and bend test, shall show a full fibrous structure, and a good ability to flow.

The difference in ductility between the longitudinal and transverse test as exemplified by the elongation, contraction and notch toughness should be noted. These specifications may be compared with the specifications issued by the U. S. Navy for a steel of approximately the same composition as the Austrian steel. The requirements are

Tensile strength, lb. per sq. in. minimum.....	130,000
Elastic limit, lb. per sq. in. minimum.....	105,000
Elongation, per cent minimum.....	15
Reduction in area, per cent minimum.....	40

These are the requirements that the test piece must meet after being cut from the metal in a direction transverse to hot working. The U. S. Navy requirements for a transverse test are but little below the Austrian requirements for the longitudinal test. The difference between the requirements for ductility as measured by the elongation and reduction in area should be noted particularly. The Austrian army requires that their so-called fibrous steels shall exceed 4 per cent elongation as against 15 per cent for the U. S. Navy and 15 per cent contraction as against 40 per cent.

Comparing actual physical properties, we will take two tests from Dr. Kothny's article, on ingot B 3, picking the best results.

FIBROUS STEEL

	Longitudinal	Transverse
Ultimate strength	124,000	134,000
Yield point	107,000	117,000
Elongation, per cent	11.5	7.9
Contraction in area, per cent	61	27
Notch toughness, kg.-m.	17.0	3.5
Fracture	fibrous	fibrous

These results are for a chrome nickel steel containing .40 per cent carbon, .42 per cent manganese, 2.54 per cent nickel and .48 per cent chrome.¹

The following test results on steel for a 6-in. C2 hoop made at the U. S. Naval Ordnance plant at Charleston speak for themselves.¹ The steel in this case was .38 per cent carbon and .72 per cent manganese, *no alloys being present*.

CLEAN ELECTRIC STEEL

	Longitudinal	Transverse
Ultimate strength	103,000	101,800
Yield point	83,000	80,000
Elongation, per cent	26	23
Contraction, per cent	53	46
Fracture	silky	silky

¹ In the physical results noted the test pieces were heat treated to obtain the best results.

It is at once apparent how much the transverse test of the fibrous steel is inferior to the clean steel, notwithstanding that $2\frac{1}{2}$ per cent of nickel and $\frac{1}{2}$ per cent of chrome should add greatly to the ductility. In fact if the fibrous steel was made correctly, the ultimate and yield point should be about the same as noted above, but the contraction in area should be close to 50 per cent instead of only 27 per cent and the elongation should be 15 per cent or greater instead of 7.9 as is the case with the fibrous material.

Conclusions Regarding Fiber.—Regarding fibrous steel, we can come to only one conclusion, namely, that this condition, formerly considered so beneficial to steel, is in reality harmful. The bad effect of fiber is readily apparent on the transverse test, this test showing how radically the so-called fiber will reduce the ductility as measured by the elongation and reduction in area.

Manganese silicate with some ferrous silicate, both in a finely dispersed form, is probably the cause of the fibrous structure. When these inclusions are greatly elongated by rolling, forging or hammering, their effect upon a longitudinal section is practically negligible, in fact, many steel men consider that a fibrous condition improves the ductility (for example wrought iron). On the transverse section, fiber exercises a particularly harmful influence, by breaking up the cohesion and continuity of the grains, it greatly reduces the ductility.

The investigation of Dr. Kothny shows beyond a doubt, that in order to obtain fiber in electric steel, it must be overoxidized; not only must it be melted with ore, but this oxidizing slag must be removed and a new one applied, one containing still more ore. We have already noted in the previous chapter the practice of melting with complete oxidation and have seen that it produces, in most cases, an inferior steel. We have attributed this inferiority to the fact that it is overoxidized and that this overoxidation produced by the use of too much oxide in melting results in a condition hard to cure; in other words, an overoxidized metal becomes increasingly hard to deoxidize as the amount of oxidation increases.

If the electric process is to build up a reputation similar to the crucible process in the production of high quality steel, it must produce steel that is sound, steel free from oxidation defects and gas, and steel in which weakening non-metallic inclusions are practically absent. Too often, in actual use, the supposedly

highest grade chrome nickel automotive steels will fail suddenly and unexpectedly. It may be definitely stated that these failures originate at a spot of weakness caused by a non-metallic inclusion which, although it may be sub-microscopic in size, is probably in such form that the cohesion of the crystals is utterly destroyed. Repeated stresses even though they be far below the elastic limit of the metal, have a cumulative effect upon this spot of weakness and a failure results. As fiber is undoubtedly the ultimate result of non-metallic inclusions, it follows that this condition is undesirable and may be harmful to an extreme in steels which must stand severe and unusual strains, and which must, consequently, pass the most rigid physical requirements. Clean steel will do this, unclean steel will not; and as we are almost positive that fiber is a condition present in unclean steel, it follows that the fibrous steel is not so good as the thoroughly clean metal.

It seems paradoxical to take clean high-grade scrap, spoil it by melting with two oxidizing slags, and then deoxidize with ferro-alloys, ignoring altogether the real advantage of the electric process, which produces clean steel from clean scrap by restricting oxidation and deoxidizing under ideal conditions. And all of the above complicated procedure is to produce a metal which has inferior physical properties. If it is desirable to overoxidize in melting and use ferro-alloys for deoxidation, why not do it in the basic open-hearth furnace where it can be done cheaply?

CHAPTER X

THE HOT METAL PROCESS

Charging and Slag Making—Deoxidizing and Tapping—Refining Blown Bessemer Metal—the Triplex Process.

The hot metal process for the manufacture of electric steel ingots consists of refining a charge of metal which has been melted and partially refined by some other process. The hot metal process is especially adapted to the manufacture of the various alloy steels in much larger tonnages than is possible in the cold scrap process. Steel made by the hot metal process is much cheaper than cold scrap electric steel as the expensive melting costs are eliminated. Likewise, the violent current surges, present in the melting period and responsible for the high demand charges placed upon the electric steel plant by the central station, are also eliminated.

Electric steel made by the hot metal process and poured into ingots is nearly always produced in furnaces of comparatively large size, up to 30 or more tons. Recently¹ a 60-ton furnace was contracted for, which will soon be in operation. The Heroult furnaces now operating on hot metal are rated as 15 to 30 tons. They are nearly always overcharged, commonly 25 per cent, sometimes 50 to 75 per cent. Later in this section we will present a furnace log of a 95-ton heat of chrome nickel armor plate made in two 30-ton furnaces. This degree of overcharging is somewhat unusual; it is common, however, to tap 80,000 lb. from a 30-ton furnace.

Hot metal electric steel does not have such a good reputation for quality as that produced from cold scrap in the smaller furnaces. Nine out of ten purchasers will prefer cold scrap electric steel to that made from hot metal. If they are asked why they prefer it they will all maintain that it is more sound. In most cases it is. There are four reasons for this: First, because many times it is overoxidized in melting; second, because it is more difficult to deoxidize properly in the 25- or 30-ton furnace

¹ April, 1923, see p. 95.

than in the 6-ton; third, because most melters on hot metal furnaces are former open-hearth men—the electric steel industry is so young that few furnacemen have worked on this type furnace to the exclusion of any other—and consequently do not realize the full possibilities of the process and are not familiar with the basic principles that underlie deoxidation; and fourth, because, until recently, large furnace installations were confined to plants whose motto, even if they would not admit it, was, “tonnage first, cost second, quality third.” Accustomed to making steel on a tonnage basis as cheaply as possible; and in addition, often operated as an adjunct to the open hearth; they tried to place the electric furnace in the same category as the open hearth and consequently made an inferior, or at best only a passable, product.

The practice of refining molten open-hearth metal in an electric furnace is very often spoken of as duplexing. This is unfortunate as the same term is applied to the refining of blown Bessemer metal in the tilting open hearth. We have, therefore, spoken here of the practice in which the electric furnace refines molten open-hearth metal as the hot metal process in order that no confusion will ensue. When the electric furnace is the final step of a three furnace process, *i.e.* Bessemer to open hearth to electric furnace, we may very properly and without ambiguity speak of it as the triplex process.

The hot metal process may be divided into two distinct steps: (1) Charging and slag making and (2) deoxidizing and tapping.

CHARGING AND SLAG MAKING

The method of charging the furnace differs depending on whether the hot metal is obtained from a furnace in the same building, or whether it must be hauled from another part of the plant. In most cases where open-hearth metal is used, the electric furnaces are located adjacent to the open hearth. When Bessemer metal is refined the electric furnaces are, on the contrary, often at some distance from the converter building. The description of charging in this latter case will be properly postponed until we take up the refining of Bessemer metal in a later section.

Slag making in the hot metal furnace depends on the metal used. If open-hearth metal is charged, the oxidizing slag is

necessarily omitted as all oxidizable elements including phosphorus have been removed in the open hearth. Therefore the electric furnace must only deoxidize and desulphurize. With Bessemer metal both oxidizing and deoxidizing slags must be used. This practice will be described later.

Charging the Furnace.—After making the necessary bottom repairs—200 to 500 lb. of dolomite or magdolite are used—the furnace is ready for charging. A spout is placed in position, (Fig. 33,) and the open-hearth metal brought to the furnace in



FIG. 33.—Charging a 30-ton electric furnace with molten open-hearth metal.

a bottom pour ladle by a traveling crane. After spotting the ladle properly over the spout, the nozzle is opened and the metal allowed to run into the furnace through one of the doors (Fig. 33).

There are two methods of charging; both have their disadvantages. Using a bottom pour ladle as shown in Fig. 33 the weight of the metal going into the furnace must be estimated; although later, if nickel steel is made, the exact charge can be figured from the percentage of this element present. By using a lip poured transfer ladle which may be run over a track scale and weighed, the slag must be raked off by hand-rabbling before the metal can be charged into the furnace; a hot and disagreeable

job at the best. None of the open-hearth slag which is high in oxides should be permitted to get into the electric furnace, as it only increases the difficulty of deoxidation.

In making heavy ordnance by the hot metal electric process, the contents of a 75-ton open-hearth furnace is tapped and transferred to the electric furnaces, about half of the heat being poured into each. Using the same size nozzle in the ladle and knowing the charge in the open-hearth furnace, it becomes easy, after a little experience, to judge when just about half of the metal is poured. After pouring is complete, the slag is made and the metal deoxidized as described below.

Composition of the Metal Charged.—The operator on the electric furnace usually orders the open-hearth furnaceman to supply him with hot metal of a definite composition. The carbon is kept down to such a point that, after all metallic additions to the electric heat, the metal will require little if any recarburizing. We have seen in the previous chapter that it is undesirable to recarburize electric steel in the ladle. Although some recarburization may be accomplished by washed metal or pig iron this is kept to a minimum.

In good electric furnace practice, the open-hearth metal is deoxidized as much as possible before being poured into the electric furnace. To this end, ferromanganese and usually ferrosilicon are added to the metal in the ladle while tapping the open hearth. As not more than 10 min. elapse between the tapping of the open hearth and the charging of the electric furnace, insufficient time is allowed to insure the steel being clean, but deoxidation is accomplished to some extent and the work thrown on the electric furnace white slag thereby lessened.

In making alloy steel, nickel scrap may be charged into the open-hearth furnace. No alloying additions, however, are ever made to the open-hearth metal except perhaps ferromanganese and ferrosilicon, all of the alloys are reserved for the latter part of the electric furnace deoxidation period.

The greatest source of trouble to the electric furnace melter at the beginning of the heat comes from too cold open-hearth metal. Unless both furnace and metal are hot, it will skull around the outer circumference of the hearth and will be melted off with some difficulty, and at a waste of time and power.

In general, for best results the molten open-hearth metal should contain: Carbon, 10 to 25 points below the final requirements;

manganese, .15 to .30 per cent and phosphorus under .020 per cent preferably under .015 per cent. Silicon will be practically nil and sulphur may be present in any amount up to .08 per cent. Above this point, desulphurization becomes somewhat of a problem.

Preliminary Slag Making.—As the molten metal is flowing into the electric furnace through one door (Fig. 33), the first and second helpers are shoveling lime in through one of the other working doors. By the time the metal is all charged, 500 to 1,000 lb. or more have been added. (See Log Sheet 5.) While the metal is running into the furnace, ferrosilicon (50 per cent silicon) is sometimes added in small doses into the spout, where it is readily dissolved by the metal. This serves to eliminate any wildness.

After charging is complete, sufficient fluorspar, 100 to 200 lb. is added to thin the lime, the doors are closed and full power is put on the furnace to melt the metal and slag as soon as possible. If both metal and furnace were hot, and no skull has formed on the bottom or near the banks, 30 min. on high power will be sufficient to put both metal and slag in condition for deoxidizing.

It will be at once noted that white slag-making in the big furnace is accomplished differently from the 6 ton. In the latter the white slag, already mixed on the shop floor, may be shoveled onto the bare bath of metal after the black slag is taken off. In the cold scrap process, the bath is necessarily hot and the conditions are good for the immediate formation of a white slag. The big furnace which has been empty at least 20 min., has cooled appreciably; also the transferred open-hearth metal is often on the cold side. The metal after charging even under the best conditions, if not actually frozen around the edge of the bath, is somewhat mushy. This condition, together with the larger circumference of the bath, makes it advisable to build up the slag in the furnace, instead of mixing it on the floor.

DEOXIDIZING AND TAPPING

After the metal and slag have become hot, we have in the furnace a bath of partly oxidized metal covered by a slag consisting principally of lime, thinned by a little fluorspar. The slag is dark and in most cases thick and viscous especially when the furnace is cold or only a small amount of spar was used. We are now ready for deoxidation.

Deoxidizing the Slag.—After the bath has become sufficiently heated and fluid, if nickel steel is to be made, metallic nickel is added. After this is melted, a test is taken and sent to the laboratory to be analyzed for carbon, manganese and nickel. Knowing the exact amount of nickel in the charge as determined in the last test from the open hearth, and knowing the amount of nickel added and the percentage resulting from this addition, the exact weight of the metal in the furnace is readily calculated.¹

Powdered coke is now scattered over the slag, about 100 to 200 lb. being used. If necessary, more fluorspar is added to obtain the desired fluidity. Silica sand is often used instead of fluorspar. In this case, the fluidity is obtained by the formation of calcium silicates. The question of the desirability of silica sand for use in electric furnace slags has been discussed in a previous chapter.

After 15 or 20 min. the slag becomes lighter in color changing from dark to light brown; more coke is added, from time to time, keeping the furnace on high power to promote the formation of calcium carbide. Thirty minutes further should suffice for the slag to change from light brown to white or gray, the latter denoting an excess of carbon. When a spoon containing a little slag is dipped in water a strong characteristic odor of acetylene should now be noticeable.

Because of the extended discussion of deoxidation in a previous chapter on the cold-scrap process, we will not need to dwell longer on this same procedure in the larger furnace. It is sufficient to say that when the slag contains an excess of calcium carbide it indicates that oxides are absent from the slag and, because of the migration from metal to slag to restore the equilibrium and through the area of contact between metal and slag, oxides in appreciable amounts should be almost entirely absent from the bath.

It is now only necessary to maintain the proper slag conditions throughout the remainder of the heat, *i.e.*, maintain a strongly

¹ To get the exact weight of the charge, the calculation is as follows: Assume that the last test from the open hearth taken 10 min. before tap showed a percentage of 1.70 nickel. Part of the open-hearth heat was charged into one electric furnace, melted and 1,000 lb. of nickel (99 per cent) added. After this was melted, the heat was stirred and a test taken for analysis. This was found to contain 2.80 per cent nickel. Therefore, 1,000 lb. increased the percentage 1.10 and since the nickel is 99 per cent pure 990 lb. are equivalent to 1.10 per cent of 90,000 lb. Therefore 90,000 lb. is the amount in the furnace.

LOG SHEET 5A.—FURNACE LOG SHEET OF A HEAT OF ELECTRIC ARMOR
PLATE MADE IN TWO 30-TON HERCULT FURNACES

Part A								Furnace F		(½ of Heat)			
Details of heat								Melters log					
	C	Mn	Si	S	P	Ni	Cr	Time					
Analysis ordered	.32 .40	.25 .35	.06 .18	015 less	015 less	3.50 4.00	1.75 2.25	6:26 p.m.	Started charging				
Date Furnace No. Heat No. Ingot No. Finished weight of armor ingot								Jan. 24, 1922 F 128 201(43"×90") 189,540					
Additions to furnace								8:45 p.m.		Melted—900 nickel shot			
O.H. metal								96,000		9:10 p.m.		550 ferrochrome 6 per cent C	
Nickel shot								1,240		9:30 p.m.		Rabbed—slag brown	
Ferromanganese								200		9:40 p.m.		200 lime—200 coke—100 spar	
Ferrosilicon (50 per cent)								(40)+400		10:20 p.m.		1,500 ferrochrome 8 per cent C	
Ferrochrome (8 per cent C)								2,250		10:45 p.m.		75 ferromanganese	
Ferrochrome (6 per cent C)								550		10:50 p.m.		Rabbed—slag green	
Ferrochrome (2 per cent C)								230		11:00 p.m.		200 nickel shot—second test	
Additions to slag								11:30 p.m.		Result second test C. 27 per cent			
Lime								1,800		11:45 p.m.		750 ferrochrome 8 per cent C	
Sand								200		Jan. 24th. 12:00 a.m.		500 lime—200 coke—100 spar— 100 sand	
Fluorspar								600		12:10 a.m.		Rabbed—slag carbide	
Dolomite (for bottom)								500		12:15 a.m.		Third test—100 spar	
Coke								500		1:00 a.m.		Stirred—slag carbide	
Tapped previous heat								Jan. 20, 1922		1:05 a.m.		Results third test C 34 per cent; Mn .20 per cent; Ni 3.67 per cent; Cr 1.85 per cent	
Charged from (Jan. 23, 1922)								6:26 p.m.		1:30 a.m.		Stirred—slag carbide—100 coke	
to (Jan. 23, 1922)								6:31 p.m.		2:05 a.m.		140 nickel shot	
Power on (Jan. 23, 1922)								6:28 p.m.		2:10 a.m.		400 lime—50 sand—100 spar	
Tapped (Jan. 24, 1922)								3:19 a.m.		2:15 a.m.		125 ferromanganese	
Length of heat, hours								8.9		2:25 a.m.		Power off 5 min. to lower electrode	
Heat test in seconds								10		2:30 a.m.		Stirred—slag carbide	
Temperature at tap								2,840 deg. F.		2:43 a.m.		230 ferrochrome 2 per cent C	
Temperature of ingot No. 201								2,090 deg. F.		2:55 a.m.		400 ferrosilicon	
Meter at tap								8,968		3:00 a.m.		Stirred—slag carbide	
Meter at charge								8,842		3:07 a.m.		Set test 10 sec.—heat quiet	
Total K.W.H. used								12,600		3:12 a.m.		Set test 10 sec.—heat quiet	
K.W.H. per ton								258.35		3:15 a.m.		Set test 10 sec.—slag O. K.	
No. of heats roof								2		3:16 a.m.		Power off	
No. of heats lining								41		3:19 a.m.		Heat tapped	
New electrode No. 3								24 in.					
New electrode, weight								1,823					

REMARKS.—Teen in 100-ton ladle with furnace H—2½ in.—nozzle—light bottom skull in ladle—light skull in furnace—condition bottom and lining O.K.

Analysis of ingot.						
C	Mn	Si	S	P	Ni	Cr
.38	.32	.173	.009	.013	3.71	1.90

LOG SHEET 5B.—FURNACE LOG SHEET OF A HEAT OF ELECTRIC ARMOR
PLATE MADE IN TWO 30-TON HERCULT FURNACES

Part B								Furnace H		(½ of heat)	
Details of Heat								Melters log			
	C	Mn	Si	S	P	Ni	Cr	Time			
Analysis ordered	.32 .40	.25 .35	.06 .18	.015 less	.015 less	3.50 4.00	1.75 2.25	6:15 p.m.		Started charging Added 25 lb. ferrosilicon	
Date	Jan. 24, 1922							6:25 p.m.		First test—added 300 lime	
Furnace No.	H							6:35 p.m.		Added 500 lime—100 spar	
Heat No.	128							6:40 p.m.		Metal cold—heavy skull	
Ingot No.	201(43"×90")							7:00 p.m.		Results first test: C .13 per cent; Mn .23 per cent; Ni 2.72 per cent	
Finished weight of armor ingot	189,540							8:00 p.m.		Skull melted—nickel 1,000 lb.	
Additions to furnace								8:45 p.m.		Lime 500—coke 200—sand 200	
O H. metal	91,000							9:15 p.m.		1,000 ferrochrome, 8 per cent C	
Nickel shot	1,180							9:45 p.m.		670 ferrochrome, 8 per cent C	
Ferromanganese	142							10:00 p.m.		100 lime—200 spar	
Ferrosilicon (50 per cent)	(25) +370							10:10 p.m.		Rabbled—slag white	
Ferrochrome (8 per cent C)	1,670							10:18 p.m.		Rabbled—slag white	
Ferrochrome (2 per cent C)	1,000							10:20 p.m.		Second test—added 200 coke	
Additions to slag								10:45 p.m.		Results second test: C .31 per cent; Ni 3.77 per cent	
Lime	2,000							11:00 p.m.		500 ferrochrome, 2 per cent C	
Sand	300							11:20 p.m.		500 ferrochrome, 2 per cent C	
Fluorspar	500							Jan. 24			
Dolomite (for bottom)	600							12:00 a.m.		Added lime 200—spar 100	
Coke	600							12:05 a.m.		80 ferromanganese	
								12:25 a.m.		Third test—200 coke	
Tapped previous heat	Jan. 20, 1922							12:40 a.m.		Rabbled—slag carbide	
Charged from (Jan. 23)	6:15 p.m.							1:00 a.m.		Rabbled—added 100 sand	
to (Jan. 23)	6:25 p.m.							1:30 a.m.		Results third test: C 38 per cent Mn .25 per cent; Ni 3.62 per cent; Cr 1.95 per cent	
Power on (Jan. 23)	6:19 p.m.							2:00 a.m.		Rabbled—added spar 100—lime 400	
Heat tapped (Jan. 24)	3:23 a.m.							2:45 a.m.		180 nickel shot—62 ferromanganese	
Length of heat (hours)	9.1							2:55 a.m.		370 ferrosilicon	
Heat test in seconds	9							3:03 a.m.		Set test 9 sec—medium skull	
Temperature at tap	2,797 deg. F.							3:14 a.m.		Set test 9 sec.—metal quiet	
Temperature of ingot 201	2,690 deg. F.							3:16 a.m.		Power off	
Meter at tap	8,625							3:23 a.m.		Heat tapped	
Meter at charge	8,498										
Total kw.-hr. used	12,700										
kw.-hr. per ton	276.08										
No. of heats roof	27										
No. of heats lining	45										
								Pouring practice			
Total charge	95,362	Started pouring		3:28 a.m.	Held in ladle		5 min				
Ingot weight	92,000	Finished pouring		3:40 a.m.	Time in mold		10 7 hr.				
Scrap (pit and ladle)	900	Rate of pouring,			Style mold		43×90				
Furnace loss	2,462	lb. per min.		15,795	Hot top		42×33×90				

REMARKS.—Teem in 100-ton ladle with furnace F—2½-in. nozzle—light bottom skull in ladle—heavy bottom skull in furnace—condition bottom and lining O.K.

Analysis of ingot.

C	Mn	Si	S	P	Ni	Cr
.38	.32	.173	.009	.013	3.71	1.90

reducing condition through the presence of .50 to 3 per cent calcium carbide.

Adding Alloys.—The deoxidation of the bath should be practically complete within 30 min. after the slag shows the presence of carbide. As soon as there is carbide present alloying additions may be made as rapidly as possible; the only precaution necessary is against chilling the bath too much at this point. Only in the case of ferrovanadium is the alloy added toward the end of the heat.

From Log Sheet 5¹ an idea can be gotten of about the rate in which the alloys are added. In the case of ferrochrome and ferromanganese close to 100 per cent will go directly into the metal. It occasionally happens that, after an addition of chrome the slag will show a greenish tint due to a small amount of the metal oxidizing to Cr_2O_3 . A few shovelfuls of coke scattered on the slag will reduce this oxide, driving the metal into the steel.

Because of its large area, the bath in the hot metal furnace, in contrast to the smaller size, should be rabbled frequently. This is especially necessary to keep the slag in condition, as atmospheric oxidation near the doors tends to prevent the formation of calcium carbide. This is one of the difficult jobs in deoxidizing in the large furnace. It is easy to keep the slag in shape where it is acted on by the arc or in the region of high temperature near the arc. The use of considerable powdered coke at all times in the hot metal furnace, even at the risk of absorption of carbon by the bath is recommended.

¹The heat outlined in Log Sheet 5 should not be taken as representative of hot metal electric practice. In the first place, the elapsed time of this heat is much longer than would be the case if the furnaces were in constant use. Heat 128 in Log Sheet 5 was made after both electric furnaces had been idle 4 days.

In addition, making armor plate heats of 95 tons in two 30-ton electric furnaces is a somewhat radical procedure and as the heat shown in Log Sheet 5 was but the third or fourth one of this kind ever made, the furnacemen being somewhat unfamiliar with the practice had, in one sense, "to feel their way." It is obvious that the money loss if a heat of this composition and size were spoiled would be considerable, consequently the furnacemen were cautioned not to hurry.

Thirty-ton heats of electric alloy steel can be made satisfactorily in 4 to 6 hr. and have been made in this time in regular practice. The armor plate heat in Log Sheet 5 was given, not to present regular practice but to show what the big electric furnace is capable of in the line of ordnance manufacture.

Degasification.—After deoxidation is complete, it is necessary to degasify. This is not so easily accomplished as deoxidation. Even after 1 to 6 hr. under a carbide slag the metal will show a tendency to be wild; it will spark in pouring a test and will in most cases be blowy. The presence of gas in electric steel and the means of removing this harmful intruder were discussed in a previous chapter. Like the cold-scrap process, it is advisable to add the degasifying alloy, ferrosilicon, in small doses during the last 45 to 60 min. of the heat instead of right at the end of the operation which has been customary for some years. After the steel has been under the carbide slag for $1\frac{1}{2}$ to 3 hr. and is completely degasified and sound as shown by the heat test, the temperature is adjusted, if necessary, to the proper point, the ladle is placed in position, and the heat tapped.

In the hot metal process, even more than in the small furnaces, the operator should be constantly on guard against untoward incidents that will throw the slag back. Although this was discussed in a previous chapter, it is well to touch on this point again, as the continued presence of a strongly reducing slag is vital for a quality product. The slag in the big furnace is more delicately adjusted—theoretically this should not be the case, but it is a fact nevertheless—than the carbide slag in the small furnace, and is more easily influenced by any untoward conditions than in the smaller furnace. Too frequent opening of doors, a too highly localized condition in heating causing the roof to drip, or the bottom coming up making the slag viscous and introducing a certain amount of oxides into it which are present in the dolomitic refractory, any of these may cause the slag to turn at a moment's notice. The result will be a partial spoilage of deoxidation and probably a blowy, inferior steel. For this reason, it is not desirable to hold a heat in a big furnace any longer than is absolutely necessary to secure a completely deoxidized and degasified condition. When this is attained, the heat is tapped.

Desulphurization.—The hot metal electric furnace is never called upon to remove such a large percentage of sulphur as is often present in a cold-scrap charge. Consequently, desulphurization is usually very complete.¹ In one plant the open-hearth metal averaged .025 to .030 per cent, the electric furnace final slag removed all but about .010 per cent. The

¹ By reactions 3, 4, 5 and 9, pp. 152 and 156.

carbide slag can remove more than 20 or 30 points of sulphur easily, but it is rarely necessary.

In the hot metal process, desulphurization may be said to be nearly automatic. It needs practically no attention from the melter. If it should happen that high sulphur molten metal is used, desulphurization, with good practice, should be as complete

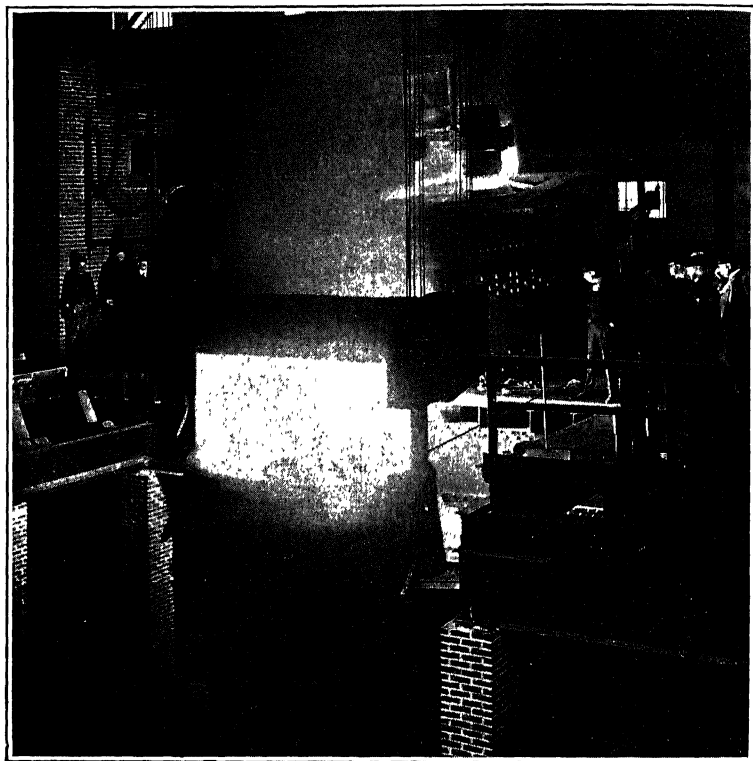


FIG. 34.—Tapping a 30-ton Heroult furnace.

with the big furnace as in the 6-ton. In any case, as we have seen in the previous chapter, the furnace operator should strive for complete deoxidation and carry at all times a slag that is strong in carbide. If deoxidation is complete, desulphurization will take care of itself.

Like the cold-scrap process it is doubtful if the percentage of residual sulphur in the metal can be brought much below .010 per cent. In fact to strive for such a low sulphur is probably a

waste of time as it has been practically proved that a percentage of as much as .030 per cent possibly higher can do no harm to otherwise good steel.

Tapping the Heat.—The operation of tapping is similar to the same procedure in the smaller furnace. The power is shut off, the electrodes are raised some 2 or 3 ft. above the bath, and the tap hole opened. The furnace is then quickly tilted until the slag line is above the tap hole, after which the metal is allowed to run quietly into the ladle (Fig. 34). After the metal is all tapped, the slag is run out of the furnace, forming a thick protecting covering for the steel. The steel which is tapped at the proper temperature is held as long as possible in the ladle, 10 min. at least, longer if possible. This is a final precaution against the presence in the metal of suspended oxides or reaction products.

Tapping temperatures vary with the composition and the grade of steel. It will be noted in Log Sheet 5 that the set tests are 9 and 10 sec. and both heats were between 2,795 and 2,850 deg. F. (1,540 to 1,565 deg. C.) when tapped; this is cold-pouring practice and is lower than usual. In the regular run of alloy steels, the heats are tapped between 2,900 and 3,100 deg. F. (1,600 to 1,700 deg. C.). While the usual tests are always used to determine the temperature of the metal; these tests are the pouring test and set test described on p. 136; most plants check the temperature of the metal when tapping and again when pouring with an optical pyrometer.

REFINING BLOWN BESSEMER METAL

It is undoubtedly best, and results in a more satisfactory practice and better electric steel, to charge the hot metal electric furnace with molten open-hearth metal. The practice of refining molten Bessemer metal was followed by one large plant a few years ago, but, at present, due to the difficulties encountered, is rarely done, at least it is rare as a regular procedure. This statement applies particularly to ingot production; the practice is more common in foundries where the molten contents of the small converter is given an additional refining in the small electric furnace.

Even though not a practical operation, we will note the details of the practice principally to view the problems involved and the difficulty of producing high-grade ingots. One of the chief

difficulties encountered is that of handling the Bessemer metal and getting rid of the acid slag which would be disastrous to a basic process.

The refining of Bessemer steel offers no especial economic advantages over molten open-hearth metal, except perhaps additional tonnage. However, when the Bessemer process is combined with the basic open-hearth, as in the duplex process and this double refined steel deoxidized and finished in the large electric furnace, then the economic advantages become recognizable. It is to the triplex process that we must look, if we expect a phenomenal growth in electric steel ingot production.

General Features of the Bessemer-Electric Furnace Practice.—For use as a base in the electric furnace, pig iron is blown down to .50 to .75 per cent carbon and tapped, the contents of one or two vessels as the case may be is then immediately transferred to the electric furnace. The temperature to which the Bessemer steel is blown depends on how far the metal must be hauled. It is always blown sufficiently hot so there will be no skulling, if possible to avoid it, either in the ladle or in the electric furnace. A regulation standard gage transfer ladle is used to transfer the metal.¹ It is run over a track scale and weighed at the entrance to the electric furnace building. After being hoisted by a crane and brought to the furnace platform, the ladle is tilted slightly and the acid slag removed by rabbling. This is one of the awkward features of this practice. It is very difficult to rabble off the slag completely from a ladle filled with hot metal and suspended by a crane in midair.

After the slag is removed, the metal is poured into the electric furnace over the top of the ladle. By the time the metal has reached the electric furnace, the carbon has been reduced somewhat due to the oxidation of this element by the oxides dissolved in the metal. It is good practice to deoxidize the Bessemer metal with ferromanganese and ferrosilicon when tapped, although to do this means a waste of both of these alloys.

The molten steel when charged into the electric furnace will contain .20 to .40 per cent carbon, no silicon, from a trace to .20 per cent manganese and all of the phosphorus, .095 per cent,

¹ This is the case when the converter building is at some distance from the electric furnaces, as in large plants. In a foundry the converters and electric furnaces are usually in the same building so a bottom pour ladle may be used.

and sulphur, .03 to .06 per cent, in the pig iron. The first slag of the electric process consisting of limestone (or lime) and iron ore or scale is thrown into the furnace, partly before the molten metal is charged; the rest being added as soon as charging is complete. The oxidizing reaction immediately eliminates the phosphorus and carbon and in 30 min. the black slag is ready to remove. This is accomplished, like the cold-scrap process by hand rabbling, another difficult accomplishment in a furnace of 15 tons or more.

After the black slag is removed the metal is recarburized and the white slag added. This is the usual composition, lime, coke, and fluorspar or sand. High power is then applied until the slag is in shape and the metal is deoxidized and desulphurized. The heat may now be finished as desired, any ferro-alloys are added, together with ferromanganese and ferrosilicon to give the desired analysis.

Advantages and Disadvantages of the Bessemer-Electric Furnace Process.—There are three points very objectionable in this process; they seem to eliminate it from the possibility of future expansion.¹ The first is the difficulty of removing the acid slag from the Bessemer metal before being charged into the electric furnace.² No one, who has not actually tried it, can realize the difficulty of facing a tilted ladle of molten metal and rabbling off the slag with a 25-lb., 16-ft. skimmer. This difficulty is increased by the necessity of removing the last traces of the slag. The objection of introducing any highly silicious slag into a basic furnace is obvious.

The next difficulty is removing the black slag. Slagging off is hard enough in a 6-ton furnace, and it becomes a test of endurance and strength to remove all of the slag from a 15- or 20-ton furnace overcharged at least 25 per cent. The large diameter of the bath contributes principally to this difficulty. In fact, slagging off in a hot metal furnace is impractical although it has been done over a long period.

Another disadvantage is the difficulty of making good electric steel by this process. It is well known that Bessemer steel is at best highly charged with oxides and gases and is consequently the poorest product of the steel making processes. With present

¹ That is, in ingot production.

² Only necessary when a standard gage transfer ladle is used.

knowledge of deoxidation, the purest base makes the best electric steel, therefore it follows that Bessemer metal makes a poor grade of electric steel. This has been proved in practice. Theoretically, perhaps practically in the next few years the direct arc furnace will produce a high grade product from a poor base. In present practice, this is not accomplished to any great extent. With these disadvantages, the refining of Bessemer metal may be dismissed as impractical at present.

There is one advantage of refining Bessemer metal in the electric furnace; that advantage is tonnage. One 15-ton electric furnace using this practice, tapped regularly eight heats averaging 40,000 lb. each every 24 hr. Operated in conjunction with a Bessemer plant, the electric furnace is assured of metal to charge as soon as a heat is tapped; the two processes synchronize perfectly, a feature that is not present with stationary open-hearth, electric furnace practice.

The Bessemer-Electric Furnace Practice in the Foundry.—The principal objections offered against the Bessemer-electric furnace process when the product is poured into ingots are not applicable to the process when used for the manufacture of castings. As handled in the foundry, this form of hot metal process becomes very successful. In the first place, the heats are small, never greater than 6 tons, often much less. Thus slagging off the metal in the electric furnace presents no problems whatever. Likewise, as both converter and electric furnace are commonly in the same building and thus served by the same crane, the metal may be transferred by a regulation bottom pour ladle, therefore the difficulty of removing the slag from the metal in the transfer ladle is entirely obviated.

The process as applicable to the manufacture of steel castings has the great advantage that the cheapness of the Bessemer may be combined with ultra-refining possible in the electric furnace to produce a product much superior to that produced by the converter. Although the Bessemer-electric furnace practice cannot, on account of the overoxidation introduced in the conversion, produce very high-grade steel, that is high grade in the sense that these words are used when applied to ingots of tool steel or as compared to the crucible process; nevertheless, the additional refining and deoxidation accomplished in the electric furnace increase greatly the quality of the castings over that possible in the Bessemer or open hearth.

THE TRIPLEX PROCESS

The triplex process, Bessemer to open hearth to electric furnace is not used to any extent to produce electric steel. In the first place it is only practicable in the very large plant, and then only when the demand for the product of the electric furnace is very large. Two 25-ton electric furnaces operated continuously 6 days a week would turn out about 150,000 tons of ingots a year. This is nearly twice the total ingot production for 1922. One plant in the Middle West is equipped to make this tonnage. It is readily apparent how great the possible tonnage of high-grade steel may be made with little extra effort.

Operating Details of the Triplex Process.—Molten pig iron is blown to the desired carbon content in the Bessemer converter and transferred to a 100- or 200-ton tilting open-hearth furnace. Manganese and silicon are eliminated entirely in the Bessemer; phosphorus is removed by means of a very basic slag in the open hearth. A convenient portion, usually 25 to 45 tons is tapped from the open-hearth furnace and charged into the electric furnace where refining is completed by deoxidizing and desulphurizing with a white slag. A 25-ton electric furnace will produce by this process about 250 tons of ingot a day.

It may be interesting to note the approximate temperatures of the metal in its progress from pig iron as cast from the blast furnace to finished electric steel.

	Deg. F.
Pig iron in the ladle.....	2,600
Mixer metal.....	2,500
Metal charged into converter.....	2,475
Metal tapped from converter.....	2,875
Metal charged into open-hearth furnace.....	2,800
Metal tapped from open-hearth furnace.....	2,875
Metal charged into electric furnace.....	2,850
Metal tapped from electric furnace.....	2,800
First electric ingot.....	2,750
Last electric ingot.....	2,700

Electric furnaces in this practice are usually located in the same building and adjacent to the tilting open-hearth furnaces simplifying the process greatly. Refining in the electric furnace is accomplished in exactly the same way as when molten metal from the stationary open hearth is used. This has been covered in detail in the earlier part of this chapter.

Advantages of the Triplex Process.—Where equipment is available—only present, of course, in the big plant—this is the ideal way to make electric steel in large lots. All of the advantages of rapid furnace operation present with the Bessemer-electric furnace practice are present here, and none of the disadvantages. It is not necessary to slag off in the electric furnace as the phosphorus is removed in the open hearth. In transferring the metal from electric furnace to open hearth a bottom-pour ladle may be used. All details of the process work in perfect harmony and unison, consequently a large tonnage is possible at a low cost.

In addition, and far more important, more attention can be paid to deoxidation as this is the only operation performed in the electric furnace. Also the metal as received from the open hearth is never as badly oxidized as it is from the Bessemer, therefore less work is thrown on the electric furnace and a better product results.

Obviously, the triplex process is only economical if pig iron is cheap and in plants operating their own blast furnaces. Power cost, one of the principal items in the manufacture of electric steel, is very low in the triplex process. Assuming that electric current is 1.5 cents a kilowatt hour—this is perhaps above the average—and that it takes 3 hr. to refine 30 tons of metal at an expenditure of 4,500 kw. hr., the cost of the power will not exceed \$2.25 per ton. Adding on refractories, labor, overhead, etc. the total base cost of refining steel (that is the metal base without alloy additions, in other words plain carbon steel) should not be more than \$5 to \$6 a ton in excess of what duplex open-hearth steel costs. And this for a steel that is at least 50 per cent better in quality. It is here that the electric process as a tonnage proposition has a practically unlimited future.

CHAPTER XI

ELECTRIC STEEL POURING PRACTICE

The Mechanism of Pouring—Mold Design—Top and Bottom Pouring Practice—Temperature and Rate of Pouring.

As the manufacture of electric steel is, to a large measure, confined to the production of the higher grade products, the correct teeming or pouring¹ of the ingots becomes of greatest importance. In open-hearth and Bessemer practice, the maker is concerned chiefly with getting out a satisfactory product at a minimum cost. To do this he combines tonnage with facilities for easy handling and casts his ingots accordingly. As the heats in the basic open-hearth product commonly are 100 tons, he must pour very quickly and in very large molds to prevent the last part of the steel in the ladle from becoming too cold. To facilitate stripping, he mounts the molds on cars large end down. He knows that in basic open-hearth or Bessemer steel, especially with the milder grades, the amount of oxidation will be such that he will have no pipe to contend with.

In the electric process the steels are well deoxidized and with a maximum tendency to pipe. Moreover, this process produces many varieties of alloy steels, a number of which are inherently tender and delicate to handle, and which crack easily unless great care is taken in the process of pouring.

In order to simplify our discussion of pouring practice, we will take up first the general mechanism of pouring, citing the process from the tapping of the heat to the stripping of the ingots. That completed, we will discuss briefly top and bottom

¹ We use the terms teem and pour synonymously in this chapter. This will greatly simplify discussion. Speaking correctly, to teem means to transfer the steel from the ladle to the mold while pour in its strictest sense is the method of teeming, *i.e.*, we speak of ingots being bottom poured or top poured. This distinction is not important and is rarely used in the mill. In fact, the practical steel man seldom "teems" his ingots, he always "pours" them. For that reason we will use either teem or pour; preferably the latter to signify the transfer of metal from ladle to mold irrespective of the method used.

pouring and the advantages and disadvantages of each, and take up at some length the important items of mold design and hot and cold pouring practice.

THE MECHANISM OF POURING

After the heat is tapped, and the metal and slag drained completely from the furnace, a few shovelfuls of lime are thrown onto the top of the slag in the ladle to aid in preventing too rapid chilling. The ladle is then raised out of the pit and held quietly for the time necessary to allow the remaining inclusions and gas to leave the steel. This time varies according to the temperature of the metal at tap and the desired pouring tempera-

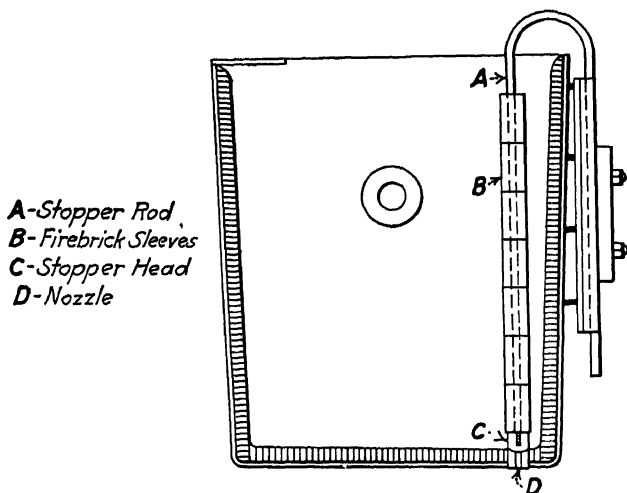


FIG. 35.—Section through a bottom-pour ladle.

ture. It may be only a minute or two, or as much as 5 to 10 min., depending on conditions. The ladle is then carried by the crane to the molds and pouring started. During the pouring of the heat, one or two metal tests are taken for chemical analysis. After all of the ingots are teemed, the ladle is taken to the slag pit and inverted to remove the slag. This is a brief sketch of the mechanism of pouring.

The Ladle.—Ladles are of the regular bottom pour type (see Fig. 35, Fig. 43, p. 252 and Fig. 44, p. 255) and are of sufficient size to hold one, sometimes two heats, with a protecting blanket of slag. They are lined with one or two courses of silica or

firebrick. To save the ladle lining, it is customary in many plants to apply a ladle wash usually of fireclay to protect the brickwork. This wash is only a thin slurry and spalls off almost immediately when the ladle is filled, thus introducing 3 to 10 lb. of foreign material usually in a finely divided state into the metal. This is one possibility for an increase in slag inclusions. It is undoubtedly best to tap the metal into a ladle having no fireclay wash. In this case, should pieces of the brick spall, it is probable that they will be of sufficient size to rise immediately to the top by gravity.

The size of the nozzle varies with the size of the heat and depending on whether the steel should be hot or cold poured. In general, American practice favors cold pouring on high grade steels so the nozzle will be sufficiently large to eliminate some of the danger from frozen stoppers and enable the whole heat to be poured rapidly and thus at nearly the same temperature. The average size nozzle for a small heat is 1 to $1\frac{3}{4}$ in.; for a large heat $1\frac{1}{2}$ to $2\frac{1}{2}$ in., with 2 in. about right.

Ladles are preheated as hot as possible before being used. The advantage of this is obvious and the extra expense well justified in every case. For heating, gas or oil is used. Most small plants use gas which, while more expensive, is more cheaply installed. The burner is arranged with a ball and socket joint so it can be let down into the ladle in order that the hottest part of the flame will be directed onto the bottom.

Pouring Troubles. Running Stoppers.—The stopper head and sleeves are changed after each heat. Particular care is necessary in setting the stopper and nozzle so that a running stopper¹ will not occur. It is customary to test each ladle just before the heat is tapped. To make this test, the stopper rod is brought down hard, forcing the stopper head into the cavity of the nozzle; in other words the ladle is shut off, and a pound or two of fine mesh, dry sand is poured around the lower end of the rod. The ladleman holds his hand beneath the nozzle to detect any sand leaking through. After the test, it is advisable to blow the sand out of the ladle with compressed air; if it is left in, as is often the case, material is available for an increase in non-metallic inclusions. The metal next to the bottom of the ladle is

¹ When the stopper head does not fit tightly into the cavity of the nozzle a stream of molten steel leaks through. This is known as a running stopper; sometimes as a leaky stopper.

always colder than the rest due to the chilling effect of the relatively large area of the bottom; in most cases, it is so viscous that the sand cannot get through it to rise to the top. If the sand is not blown out, the first 200 or 300 lb. of steel should be scrapped.

In case a running stopper develops, two alternatives are possible. The first is to carry the ladle to the pouring platform as rapidly as possible and pour the heat. This can be done unless the stopper head is completely gone and the metal is running out in a full stream. With a clever cranceman heats can be poured even though the ladleman and mold men cannot get near the ladle. If the running stopper is not too bad the ladle may be handled in the regular way as often a leak will close up after two or three ingots are teemed. In every case the advisability of pouring is left to the shop foreman who decides whether it is safe to try to save the metal. Often it is more economical, in the case of a small heat, to scrap the whole contents of the ladle than clean up the mess made in the vicinity of the molds by the splashing and spattering of the leaking stream. Running stoppers are caused chiefly by improper setting of the stopper head, sometimes by the stopper head being of inferior quality and spalling off and occasionally because the metal is so hot that the stopper head is burned completely off.

A bad running stopper is in some cases dangerous. Although precautions are widely known and practiced when this condition occurs, we can mention them here for the benefit of the inexperienced. If the shop foreman decides to attempt to pour the heat the cranceman in carrying the ladle from furnace to molds keeps it as close to the ground as he can; for, the higher the ladle is carried the more the metal will splash and of course, the greater the danger and chance of accident. In all cases the leaking stream must be kept away from any moisture, even a damp spot on the ground is likely to cause an explosion. Unless the cranceman is unusually expert a very bad running stopper is nearly always sufficient cause to scrap the metal.¹ In this case, the ladle is carried to the slag pit or other convenient spot, lowered until the nozzle is 6 or 8 in. from the ground, and the metal allowed to run out quietly into a pool that can be conveniently controlled.

¹ Occasionally it is possible to pour the metal back into the furnace.

Pouring Troubles. Frozen Stoppers.—Next to the leaky stopper, the worst calamity in pouring comes from a frozen stopper. The bottom of the ladle is always very cold compared with the molten contents and of course chills the metal next to it considerably. If the heat is tapped too cold as happens more often than necessary in many shops, the first 2 or 3 in. of metal just above the bottom will become mushy, in some cases so sticky that the nozzle is opened and closed with much difficulty. Pouring is thus hindered and a situation has arisen that demands immediate and drastic treatment. As a rule, the experienced ladleman can judge the temperature of the metal by the way the first one or two ingots pour and can, if he sees it is cold, hurry the pouring to save the rest of the heat. When the stopper has actually frozen, either of two means may be taken to open it. In the first method one of the mold men places a steel bar ($\frac{3}{4}$ in. round, about 10 ft. long) with a 6-in. right-angle bend on the end, in a position so that the 6-in. end is vertical and resting on the top of an ingot mold. The nozzle is spotted directly over this bar and the ladle lowered slowly until this 6-in. end is forced up into the nozzle, dislodging or piercing the pasty or semi-solid metal and allowing the steel to again run out. The second means is by oxygen. Either a large tank is placed permanently in the melt shop and a line piped to the molds, or a small tank weighing about 40 lb. and equipped with shoulder straps so it can be conveniently carried about is furnished. In either case, a hose from the tank or pipe line is provided having a 6-ft. piece of $\frac{1}{8}$ - or $\frac{3}{16}$ -in. pipe to supply the gas to the nozzle of the ladle. Three inches of the end of this pipe are bent into a right angle. A stream of oxygen under pressure may be directed up a nozzle filled with solid metal; the latter melts at once and allows the molten interior to run out into the mold.

If it happens that the heat is so cold that the nozzle cannot be opened at all, even to pour the first ingot, the ladle is taken back and the contents dumped over the lip into the furnace. The metal is heated up, the chemical composition readjusted, if necessary, and the bath deoxidized again. It is then tapped into a clean ladle. In any case it may be said that a condition whereby the metal is so cold that a frozen stopper results is preventable and in almost every instance is caused by carelessness or ignorance on the part of the furnaceman. We might modify this statement

slightly; with American practice on alloy steels, particularly the nickel and chrome nickel grades, the melter attempts to keep the metal just as cold as possible and yet have it pour completely. It is comparatively easy, under these conditions, to overstep the lower temperature limit causing a frozen stopper or excessive skulling.

Taking the Ladle Test.—During the teeming of the ingots, it is necessary to take the ladle or final test, the analysis of which will be representative of the average composition of the whole heat.

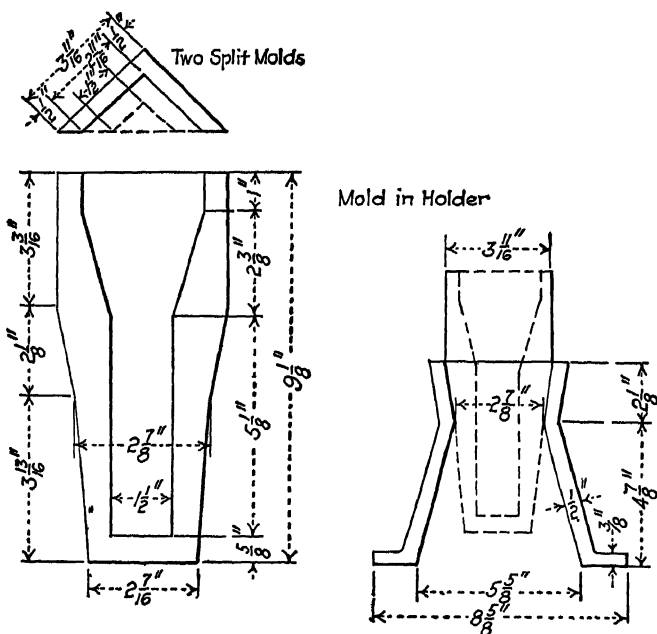


FIG. 36.—Standard ladle test mold—No. 1.

If only one test is required, it is taken after approximately half of the heat is poured. It is customary in most plants to take two tests, one when the heat is one-third and the other when two-thirds poured. Two types of ladle test molds that may be used are shown in Figs. 36 and 37.¹ With form 2 the mold is held directly under the ladle while the steam is momentarily slackened. As soon as the spoonful of metal has solidified it is knocked out, stamped with the heat number and

¹ "Methods of the Chemists of the U. S. Steel Corporation for the Sampling and Analysis of Alloy Steels," edited by J. M. CAMP, pp. 3-4, 1921.

sent to the laboratory to be drilled and analyzed. Form 1 is the most popular and perhaps the best form of test. It is a split mold, the two halves are held together by a cast iron holder or stand. With this mold a spoon is used. After a third of the ingots are teemed, the spoon is held under the ladle and the nozzle opened slightly so that no splashing occurs. When the spoon is filled, the metal is poured quickly into the mold as shown in Fig. 38. As soon as the metal solidifies, the mold is pulled out of the holder, the two halves fall apart exposing the test. The red hot piece is stamped with the heat number and sent to the laboratory where it is drilled and analyzed.

Stripping.—Practically all electric steels are poured into molds that are larger at the top than at the bottom, consequently, the regulation stripper used on Bessemer and open-hearth steels cannot be used, as the mold must be inverted to remove the ingot. Stripping is usually by a crane, by attaching chains and hooks to the chain-holds at the bottom of the mold it is inverted and the ingot slips out. Because of the inconvenience and difficulty of stripping ingots cast big end up, particular care is used in slurring

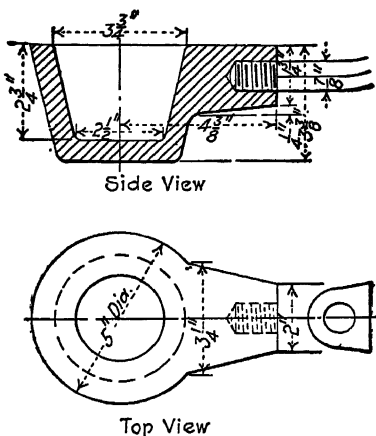


FIG. 37.—Standard ladle test mold—
No. 2.

the interior surface so that the removal will be easy. "Stickers"¹ present a difficult problem to the special steels shop and great care is therefore taken to keep the interior surface in good shape so they will be reduced to a minimum. Sticking unless caused by roughness of the mold, and this is rare, is due principally to a loose fit between the mold and stool and a resulting fin at this point. This fin can often be removed by hammer and chisel, or in some cases burned off with an acetylene torch.

The simplest method of stripping, the one practiced by many shops, is to place a hook in the molten metal after the sink head²

¹ A "sticker" is an ingot, the surface of which is held tightly by the wall of the mold and is thus removed from the mold with difficulty.

² See p. 247 for definition of a sink head.

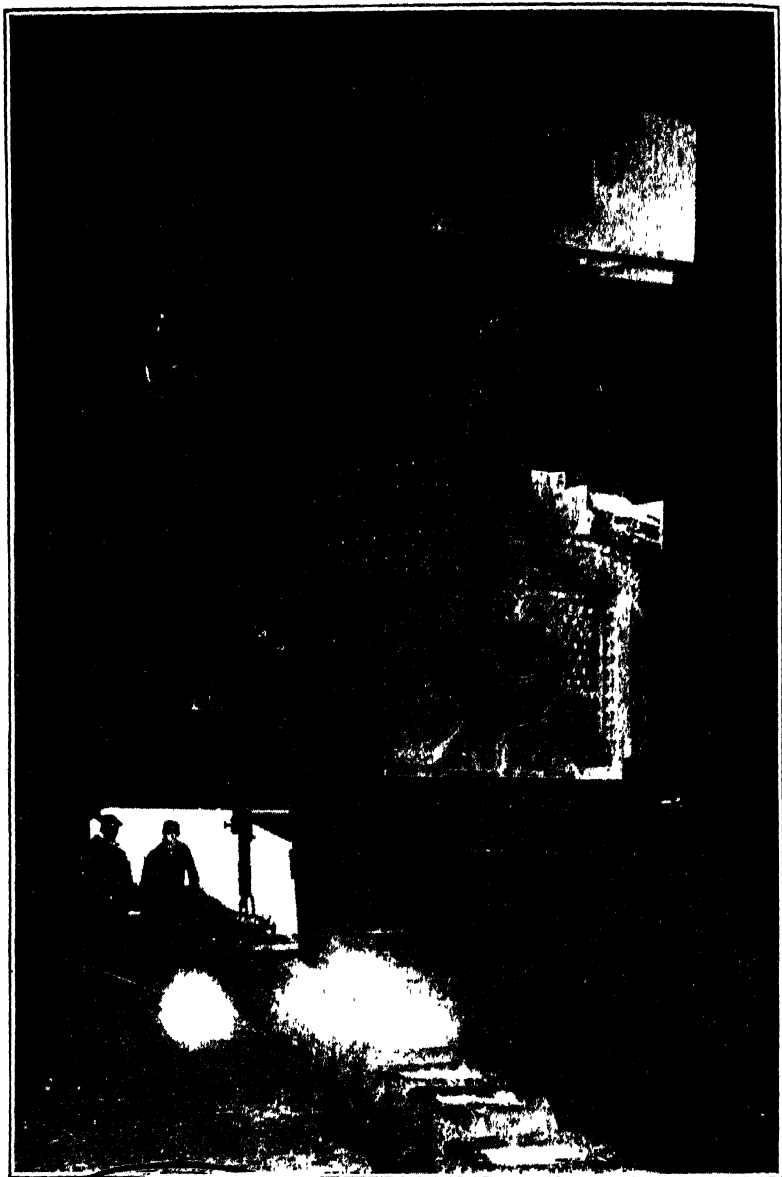


FIG. 38. Taking the ladle test.

is poured; it becomes firmly embedded when the metal solidifies and thus facilitates stripping by the easy method of hooking on a chain and lifting the ingot out of the mold with a crane. This method is of doubtful value, as it defeats in part the object of the sink head. The cold hook causes the metal, which should stay liquid as long as possible to feed the pipe, to firm over almost at once. Undoubtedly, the best method of stripping is to invert the mold removing it from the ingot, instead of removing the ingot from the mold.

Stripping is simple in the case of the split mold. This type has become very common lately for small heats and seems to be giving excellent satisfaction. The rings holding the mold in place are removed, the halves then fall apart and expose the ingot.

Pipe Eliminators.—We will not discuss pipe, as it is a necessary evil connected with electric steel manufacture, but will take this opportunity to say a few words about its elimination. In the first place, the author feels safe in asserting that practically and economically it cannot be done. The elimination of pipe has proved a fertile field for the genius of the modern steel maker. Pipe is a source of continual irritation to him. Over it he has little control, and like all other human beings, the fact that he cannot get rid of it spurs him to continued efforts to try. It is surprising how many quacks are at large in the country trying to foster on the steel mills their patent pipe eradicator. In his laboratory, the author has had the opportunity to analyze many of these cure-alls. Mostly he has found that they consist of pulverized coke or anthracite coal, some are a mixture of coke or charcoal and tar, others are composed of coke and scale (Fe_2O_4).

In his experience the author has met with two sure pipe eliminators, one was too expensive, and with the other the cure was worse than the disease. The first was a typical thermit mixture and depended for its action on the heat evolved by the reduction of iron oxide with metallic aluminum. The fireworks occurring when this mixture was placed on top of the mold was sufficient to keep the steel molten long enough to feed the pipe completely. The only fault was its cost. The other sure cure was powdered coke and kerosene oil mixed to a paste and applied to the top of the ingot. Inspection of the ingots showed that the pipe was gone, the cavity was at the extreme top of the sink head, *but* the carbon from the pipe eradicator had been absorbed in such amount, that the whole top of the ingot was highly segregated and it was

necessary to scrap just as much or more than if the normal pipe has been present. Perhaps the best method of pipe elimination is the use of heated sink heads, controlling the temperature of the metal and the rate of pouring; thus placing the pipe well up into the sink head where it can be scrapped with a minimum expense and loss.

Cooling the Ingots.—It is universally the practice in the manufacture of high-grade steel to allow the ingots to cool, usually to atmospheric temperature, before reheating for rolling or forging. Most of the special steels, especially the alloy steels, are exceedingly delicate and must be poured and handled carefully to prevent cracking and other ingot defects. In addition to the danger from cracking in the solidification of the metal in the mold, there is always present in some alloy steels a danger of cracking after solidification, if the outside surface is cooled too quickly when the interior is still very hot or pasty. To eliminate this possibility, the ingots are stripped as soon as they are all solid; that is, when there is no danger of the pipe changing location due to a shifting of the molten interior; and buried in lime or ashes to promote slow cooling through this danger range. In most special steel plants, a pit is placed conveniently where the red hot ingots may be placed and covered with ashes. Often it is sufficient to place the ingots side by side, depending on the radiated heat to keep them from cooling too rapidly.

It may be said that the precautions used in cooling the ingots carefully to prevent cracking should be likewise observed in reheating for rolling or forging. Here too rapid heating may set up strains that will crack the surface of the ingot and make the steel worthless.

MOLD DESIGN

The molds used in electric steel making are of all sizes, shapes and description. They may be round, square, octagon or corrugated and are as small as 3×3 in. for small heats of high-speed and other costly steels to as much as 43×90 for 100-ton heats of armor plate and heavy ordnance. Round molds are not favored for general practice; their use is confined principally to ingots for special purposes; armor-piercing shells is one instance where round ingots are sometimes cast. For regular practice square, octagon or corrugated molds are favored, the square type are always designed with rounded corners to reduce

cooling strains, the octagon and corrugated ingots are used for the same reason, and to reduce the forging to a certain degree.

Although the sizes vary greatly, for the 6-ton furnace the molds are usually 6×6 , 9×9 , or 12×12 ¹ the size depending upon the plant's rolling mills and the size of the finished product. For the larger hot metal furnaces any mold size may be used; it is regulated so that not more than 15 to 25 ingots are poured on a heat. More than this necessitates a steel too hot at the beginning of pouring in order that the last ingots will not be too cold.

Molds are made of a good grade of Bessemer iron and are machined until the inner surface is smooth and free from irregularities. This detail is of prime importance as an absolutely smooth surface is essential to prevent sticking, tearing and cracking.

Taper of Molds.—As before noted, all molds whether square, octagon or corrugated taper from bottom to top; the top is on an average 1 to 2 in. larger in cross-section than the bottom (Table XIV) tapering about .2 in. per foot. Some molds of excellent design exceed this figure, tapering as much as .3 to .4 in. per running foot. The function of the taper is principally to promote ease in stripping. Assuming that both ingot and mold surface are perfectly smooth, the metal will contract sufficiently in cooling to become loosened from the mold, thus when the latter is inverted, it will slip out easily. The contraction of the ingot in cooling is rarely more than just sufficient to permit this easy stripping, as neither the surface of the mold nor of the ingot is perfectly smooth. Again, this contraction is partly counteracted by the resistance to contraction of the slower cooling interior of the ingot.

Too much taper should be avoided, as it increases difficulty in forging or rolling. It is only necessary to give the mold sufficient to permit of easy stripping. Taper aids in throwing segregation and pipe well up into the top of the ingot, in many cases into the sink head where it can be cropped. It has been found in practice that the pipe is located higher and is more compact and consequently more easily rid of in ingots cast big end up, than when they are cast big end down, as in Bessemer and open-hearth practice. We may say, therefore, that the function of the taper is to facilitate stripping and control the position of the pipe.

¹ The dimensions refer to the size of the resulting ingot.

TABLE XIV.—DATA ON INGOTS

Size of ingot	Cross-section of ingot at top, in.	Cross-section of ingot at bottom, in.	Length in inches ¹	Average weight of ingot per inch of length, lb.	Total average weight of ingot, lb.
6	6	5¼	42	9	375
9	9	8	42	20	850
10	10½	9½	48	24	1,150
10	10½	9½	60	24	1,450
10	10½	9½	72	24	1,725
14	14½	13½	72	47	3,385
16	16¾	15½	72	60	4,420
18	19½	18	72	83	5,975
20	20½	19	72	96	6,910
23	23½	22	75	130	9,750
30	31	29	78	218	17,000
58 ²	about 58				120,000 ³
68 ²	about 68				162,000 ³
68 ²	about 68				213,000 ³

¹ Exclusive of sink head.² Used for ordnance.³ Estimated weight.

Square Molds.—The molds used for 6-ton heats are nearly always square. A new design is shown in Fig. 39. In addition to the rounded corners, this mold tapers and is rounded off at the bottom as shown in the illustration. A plug fits into the circular opening. An advantage of this type is that the metal is not permitted to freeze fast and be held firmly at the bottom. It often happens that the steel in solidifying attaches itself firmly to the top of the ingot at the point where the sink head joins the mold and by means of this adherence, through a fin or the irregularity at the junction of the sink head, is prevented from vertical shrinkage in cooling. If also prevented at the bottom, the skin of the cooling ingot will invariably rupture itself, resulting in a transverse crack. It is essential that vertical shrinkage be permitted to avoid cracking and this is very well accomplished in the mold shown in Fig. 39. Another advantage of the square mold is that the corners afford firm points of contact of mold and metal on four sides for the whole length of the mold

and thus prevent, to a degree at least, transverse shrinkage cracks.

On the other hand, ingots poured into square molds are more prone to develop longitudinal cracks than the octagon or another design producing a many-sided ingot. The skin of the ingot solidifying first is in the form of a square. It is contracting much more rapidly than the molten or mushy interior. A pressure on this thin skin therefore develops and as the shape is square it will not accommodate itself to this pressure as easily as if many-

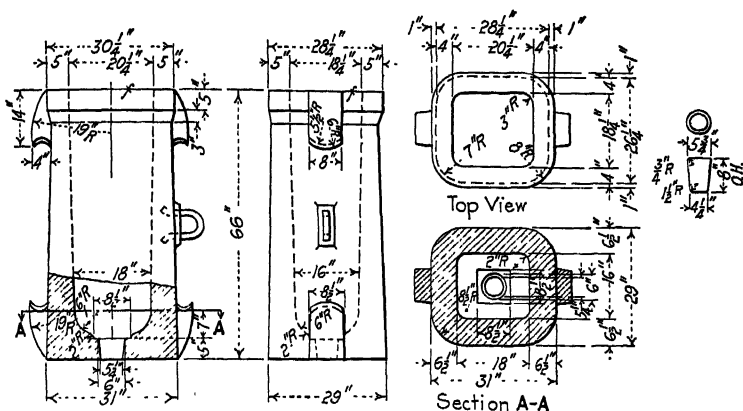


FIG. 39.—Gathmann ingot mold (patented).

sided. Thus longitudinal shrinkage cracks may develop. We will see later that shrinkage cracks are to a large measure caused by the pouring temperature. The chances of this defect being present, assuming that the pouring temperature is right, are increased by the square mold and decreased by the octagon and corrugated designs. Square molds are more apt to develop an undesirable ingot structure than octagon or corrugated. This is due to the rapidity by which the corners solidify resulting in planes of weakness running from corner to corner. Rounding off the outside corners of the mold thus making the mold wall thinner at the corners will partly correct this.

Split Molds.—Square molds of the Gathmann type in which the bottom is closed, except for a hole into which a cast-iron plug fits tightly, are difficult to keep in good condition. Slurring and smoothing the inside walls are much simpler when the mold is open at both ends. In this latter type, conditions are more favorable for careful maintenance, thus their life is longer and

costs lower. To eliminate this difficulty present in molds of the Gathmann type, prolong the life of the molds and produce ingots with better surface by more careful slurring the split mold has come into extended use. This mold is only practical in small size ingots; it is troublesome to set up in sizes greater than 9×9 . The split mold consists of two halves held together at top and bottom by rings and wedges. They are ideal in many ways, they can be carefully cleaned and completely slurred, and stripping difficulties are unknown. They have one great disadvantage. The mold is somewhat difficult to set up properly. If the edges of the two pieces do not fit perfectly, the resulting ingot will have a fin on two opposite corners. These fins are usually slight and

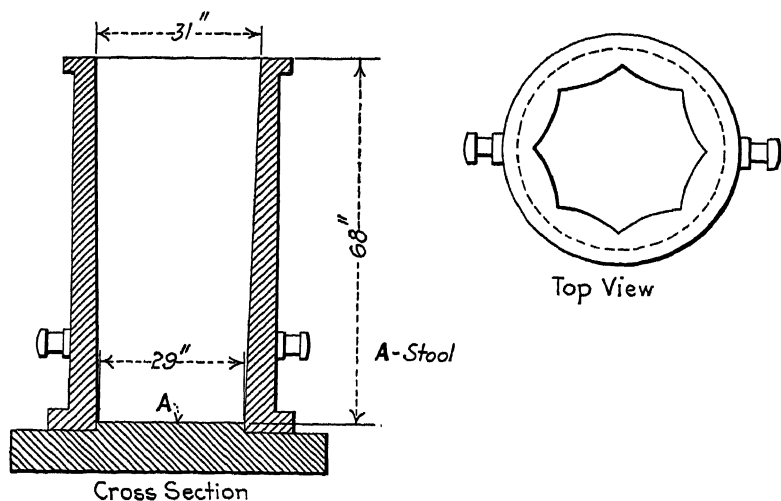


FIG. 40.—Mold for 30-in. octagon ingot.

are easily and cheaply chipped off. No doubt the advantages of the split mold for shops pouring 9×9 or 6×6 ingots are sufficient to give them preference over the Gathmann or other square molds of its type.

Octagon and Fluted Molds.—There is no question but what the octagon and fluted mold, provided the latter has not too many faces, produces the best ingot. In these types, the solidified skin has the maximum accommodating shape. Longitudinal cracking is thus reduced to a minimum. The octagon, like the square mold, has the corners to act as ties for the solidifying metal over the whole vertical distance, thus preventing, to some extent,

transverse cracking. The octagon mold has the additional advantage of four more corners than the square. Although fluted ingots having up to twelve faces are in common use, there is apparently no advantage in increasing the number of sides above eight. In addition increasing the number of sides brings the shape of the ingot nearer to a circle which form has the least accommodating shape.

Octagon and other many-sided molds are sometimes difficult to slur properly. The best results are obtained with a thin mixture of bone graphite and water. Even with all precautions "stickers" are more frequent and the ingot surface not so good as is the case with square molds.

Sink Heads.—The sink head is that portion of the ingot at the top that is poured last, often though not necessarily of smaller cross-section than the rest of the ingot and designed to provide as much sound metal as possible by bringing pipe and segregation up out of the body of the ingot proper. It is often called the hot top. For the sink head, hollow brick of the same or smaller cross-section are placed on top of the mold (see Fig. 43, p. 252). Recent molds are designed somewhat as shown in Fig. 41, thus allowing the sink head to rest on the offset.

A tight fit is desirable between the mold and the bottom of the sink head to prevent as far as possible the formation of a fin at the junction.

It is very desirable to heat the sink head to a high temperature before placing on the molds. One shop used for this purpose a gas fired muffle furnace in which the brick attained a temperature of approximately 1,600 deg. F. This practice is recommended. To protect the brick from cracking and falling apart after being filled with metal, they are often bound with one or two turns of wire. The brick crack in nearly every case and can be used only once.

The pipe or contraction cavity always forms in that part of the ingot last to solidify. In steel poured correctly this will be at the top of the ingot. By keeping the upper part of the ingot liquid and feeding the molten metal down as the interior cools and shrinks, this contraction cavity is thus thrown high up, preferably out of the body of the ingot and into the sink head. The pipe carries most of the segregation with it; thus after rolling, forging or other hot-working operation, if the sink head is cropped these defects will be largely eliminated.

To control the position of the pipe, the top part of the mold is cast with thinner walls than the bottom and the sink head made of refractory material and thin to keep this part of the ingot molten as long as possible. In nearly every plant, some substance is placed upon the top of the sink head to further insulate the metal from the cool air. This may be lime, coke or a mixture of lime and coke. We have already seen, though, that pipe cannot be conveniently eliminated; it is therefore necessary to control

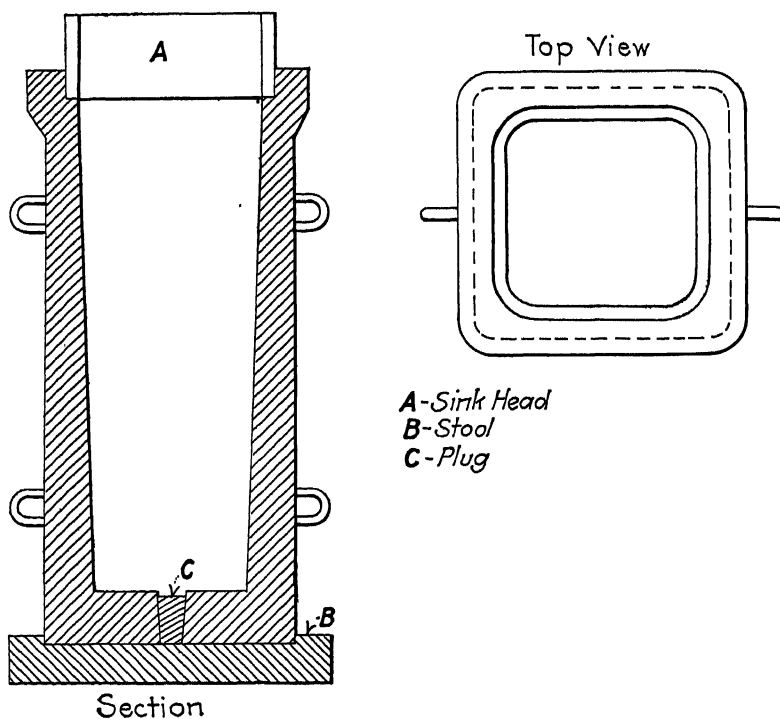


FIG. 41.—Section through a square mold and sink head.

its position so that it will be in that part of the ingot where it will do the least harm, and where it may easily be disposed of after rolling.

Slurring.—We have already had occasion to refer to the process of slurring. This consists of depositing on the inside surface of the mold, in a very thin continuous layer, some substance by which the steel will be prevented from sticking to the mold. In

addition, this slurry serves to fill up any minute holes, depressions, or inequalities of the mold wall and thus improves the surface of the ingot.

Many combinations are used for slurring, in fact practically every shop has its own methods. The most common is a mixture of graphite with either water or a light oil such as kerosene. This is applied with a long-handled brush. The heat of the mold drives off the water or volatile constituents in the oil and leaves a thin continuous film of carbon. Another favored slurry is a mixture of tar and light oil, heated, mixed and applied with a brush. Some melters "smoke the molds." For this purpose they are placed upright on parallel rows of rails, and wood, rosin or other substance producing a heavy black smoke is burned under them. This method deposits a layer of soot on the inside surface. It is not so sure a method for the formation of a continuous layer of carbon as graphite and oil.

TOP AND BOTTOM POURING PRACTICE

Two methods of pouring are in common use, top pouring and bottom pouring. Each has its advantages and disadvantages which will be noted briefly. In addition to these two methods, a special procedure is sometimes used for pouring special products, for example ingots for hollow drill steel, very large ordnance ingots etc. There are also special methods of top pouring among which may be mentioned box or pot pouring, pouring in pairs, pouring in fours, etc.

Ingots less than 12×12 in size are almost always top poured, ingots ranging from 12×12 to the largest ones of 100 to 200 tons may be top poured, bottom poured or both. The variations of top pouring, *i.e.*, box or pot pouring, series pouring, are used principally in an effort to overcome some of the inherent disadvantages of the method; improve the surface, and eliminate scabs, cold shuts and other surface defects.

Bottom Pouring.—In bottom pouring, four to eight ingot molds of the same size are arranged on a large circular, hexagonal or octagonal cast-iron base. They are connected by fireclay or silica runner brick and are all poured at the same time through a central spout or riser. The arrangement of the equipment is clearly shown in Fig. 42.

Bottom pouring has the following advantages:

(1) The top surface of the rising metal in the mold is undisturbed by the impact of the stream from the ladle consequently there is no churning or splashing.

(2) Molds receive less wear especially at the bottom which is not corroded by the impact of the stream.

(3) All of the heat may be poured at once and as rapidly as desired; the rate of filling is the same for all of the ingots and

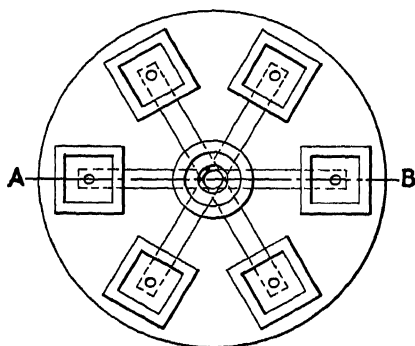
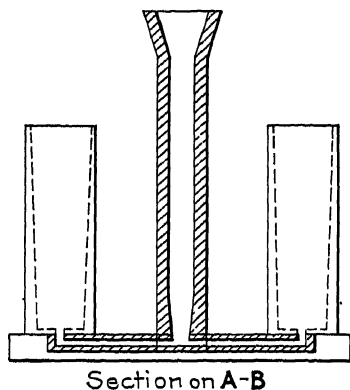


FIG. 42.—Arrangement of molds for bottom pouring.

the temperature is the same for all. In addition, the surface of the rising metal may be watched closely without interference by the ladle. This third advantage is most important.

Bottom pouring has its disadvantages as well:

(1) It is more expensive due to the complicated equipment necessary and the extra labor involved in setting it up and tearing it down after each heat is poured.

(2) When the shop is making a large tonnage of electric steel, so many sets of molds must be set up at once that it takes much floor space.

(3) All the metal in the runners is scrap and must be dug out after each heat. This is of consequence only on small heats.

(4) Unless the molds are set up carefully, breakouts are apt to occur. Likewise in pouring steel a little too cold runners will sometimes freeze.

(5) There is always possibility of runner bricks spalling, thus increasing the number of inclusions in the steel. Care must also be taken to see that the whole equipment after being set up is clean and free from dirt which would, of course, be taken up by the metal in its passage through the runners.

(6) It is claimed by some, no doubt rightly, that an excess of heat is supplied to the bottom of the ingot while the top is comparatively cool and that this condition aggravates the tendency of the steel to pipe, especially below the sink head. It is also claimed that bottom pouring increases the chance of secondary pipe formation.

Top Pouring.—Top pouring does not need detailed description. The ladle is spotted directly over the center of the mold and the ingot poured at the desired rate. (See Fig. 43 and Fig. 44, p. 255.)

The outstanding advantage of top pouring is the feeding of the hottest metal at every instant during the pouring of an ingot onto the top where it can fill any shrinkage cavity thus producing, under proper conditions, an ingot of solid, dense metal all the way to the sink head. Top pouring lessens the possibility of secondary pipe¹ and throws the main pipe into the sink head where it may be scrapped.

The other advantages and disadvantages of top pouring are just the converse of those enumerated under bottom pouring. Summing up the relative advantages of top and bottom pouring it may be said that:

(1) Bottom pouring produces an ingot of better surface; permits a number of ingots to be poured at once and at the same temper-

¹ Secondary pipe is a shrinkage cavity well down in the body of the ingot as distinguished from the main pipe that is located at the top in the sink head.

ature, and is less destructive to molds; but it also increases the possibility of secondary pipe or of the main pipe extending down into the body of the ingot thus causing unsound steel. In addition, it is more expensive and difficult of manipulation.

(2) Top pouring tends to produce a rough surface on the ingot due to splashing, cold shuts, etc. and is more destructive to molds. However, it produces an ingot more apt to be thoroughly sound internally with practically no chance of secondary pipe. Also,

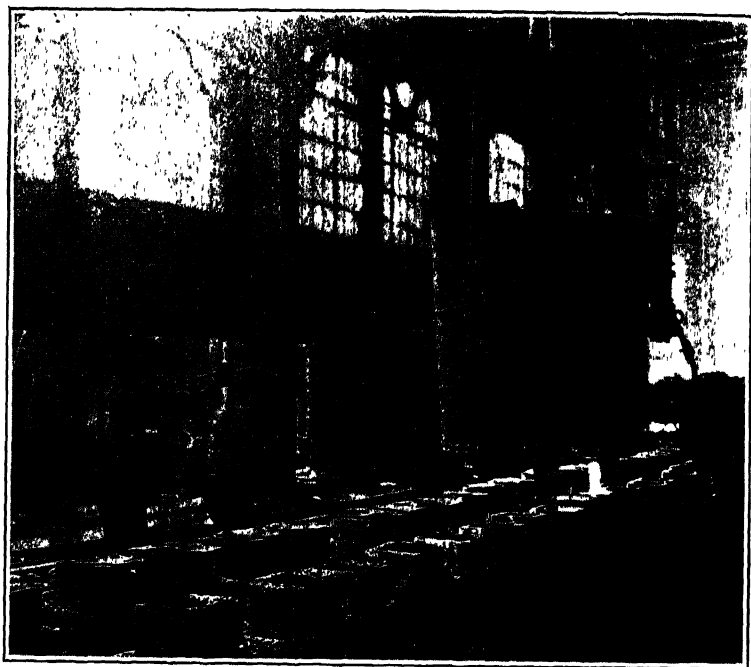


FIG. 43.—Top pouring a 6-ton heat.

there are no additional inclusions incorporated into the metal in pouring as may happen when runner bricks are used.

It is altogether possible that the advantages of top pouring, even when cost is not so important as quality, outweigh the advantages of bottom pouring. This is an open question and one which has never been satisfactorily settled. To the shop that has practiced bottom pouring for a number of years, to change would probably result in the production of steel inferior

to their present product. Consequently, many plants still bottom pour even though the costs are greater.¹

Miscellaneous Methods of Top Pouring.—Manufacturers of electric steel especially tool steel makers producing heats of 6 tons or less have tried to overcome some of the disadvantages of top pouring by using a box or pot between the ladle and the mold. If a pot is used, it may be a 50-lb. crucible pot with a hole drilled in the bottom slightly smaller in size than the nozzle of the ladle. Instead of the pot, a sheet-iron box lined with silica brick and containing a nozzle is often used. The pot or box may be hung from the ladle or suitably supported over the molds. In one plant, a large brick-lined box was mounted on wheels and rails directly over the mold pit. This box contained four nozzles by which four 9 × 9 ingots were poured at the same time. Pot or box pouring is intended to eliminate some of the force and resulting splashing that occurs in regular top pouring. By having a slightly smaller hole or nozzle in the pot a slow steady stream, without the immense pressure of the tons of metal above it, may be directed down into the exact center of the ingot mold. The metal can be fed to the pot from the ladle as needed.

The function of the box or pot in acting as a secondary ladle is of limited application, and has so many disadvantages that its use has not become extensive. Chief among its disadvantages is the liability of the hole or nozzle in the box to freeze. Even though heated very hot before use the box or pot is so much colder than the metal that it tends to chill it excessively; because it has not the large volume of molten metal present to partially counteract this chilling, as is the case with the very much larger ladle. Although there is no doubt but that better surface results, the difficulties attending successful pot pouring are many, so many that it is hardly worth while as a regular practice.

Pouring Ingots for Hollow Drill Steel.—A method of pouring ingots for hollow drill steel recently developed by an Eastern electric steel plant is worthy of mention.² A high-grade low carbon steel tube which has been cleaned and freed from scale by a sand blast is filled with sand which is packed tightly to

¹ This is more particularly the case with the manufacture of ordnance by the acid open hearth. Most electric furnace plants top pour, although some making gun steels during the war favored the other practice.

² ARMSTRONG, P. A. E., Drill Steel from Hollow Ingots, *Chem. Met. Eng.*, 24, 960-964, 1921.

exclude air thus preventing oxidation and scaling on the inside. It is inserted in the ingot mold, and hot metal is cast around it in the usual manner. The ingots are rolled to finished size and the sand extracted. The writer of the article states that this method is superior to the usual practice of rolling pierced billets as no decarburization of the center results. The steel tube in the center increases the diameter of the center hole on freezing, therefore tends to overcome shrinkage cracks and strains. It is stated that there is greater freedom from external and internal straining due to a more uniform cooling rate, and an inherent smaller crystal size and less liability for the steel to crack on the inside of the hole during forging and hardening. It is also stated that harmful segregation resulting in weakness of the wall of the hole will be absent.

Pouring Large Ingots for Ordnance.—The very large ingots for the manufacture of heavy ordnance often require special pouring methods. The problems involved in handling these large ingots are more often met with in acid open-hearth steel than in electric, as the latter has not yet been made in larger lots than 90 to 100 tons. At the U. S. Naval Ordnance plant, where these 100-ton electric heats were made, all of the ingots were top poured. Figure 44 shows one of them, a heat of armor plate. The ladle contained the combined contents of two 30-ton furnaces holding about 98,000 lb. each. The total ingot weight was 193,000 lb. A pit was necessary in which to set up the mold, which in this case, was more than 12 ft. high. At present brick hot tops are not available for these large size ingots so they are constructed on top of the mold from sand or from brick-lined sheet iron. In acid open-hearth practice the large armor ingots are sometimes both top and bottom poured. This is a successful procedure and will probably be used for electric steel when this method becomes standard for guns and armor plate. Two ladles are used. Bottom pouring is started first and continued until the mold is about one-third full. Completion is by top pouring. The splashing common with a top filled ingot is absent here as the pool of metal from the bottom pouring prevents this undesirable condition.

Armor-piercing shells are occasionally poured into round tapered molds. The mold is 12 to 20 in. in diameter at the top and tapers gradually to a 4-in. tong-hole at the bottom. These ingots, because of their shape need little forging. For

that reason the resulting shells are not as good as those made from a regular ingot, and worked down to shape by forging, as they do not get sufficient work to break up the columnar ingot structure.

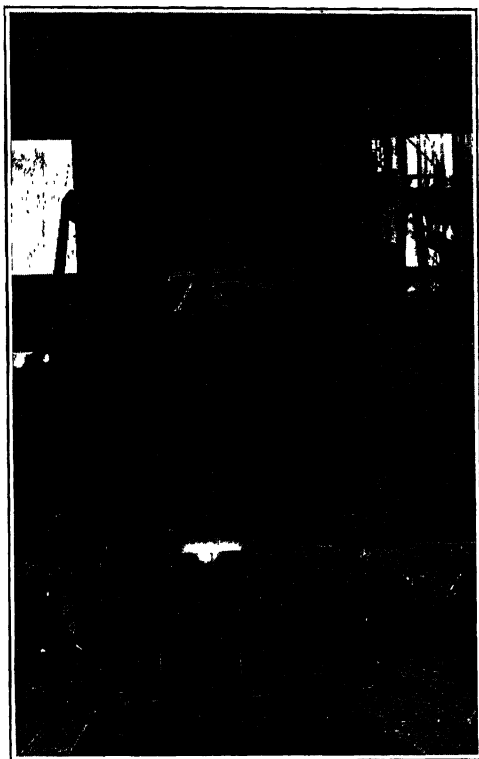


FIG. 44.—Pouring an armor ingot.

TEMPERATURE AND RATE OF POURING

It has been mentioned several times in the foregoing pages that American practice favors cold pouring. This is true with alloy steels, particularly those containing nickel. As the question of hot and cold pouring is intimately connected with the final quality of the metal, we will look at both sides of the question in the present section. Not only does the temperature of the metal influence the final quality, the rate of pouring is nearly as important. It is evident that if a hot steel is poured very slowly, we might say infinitely slow, it will be the equivalent

of cold pouring. Also a cold metal will be made colder by slow pouring, but naturally cannot be made hotter even by the most rapid pouring. As cold pouring is the most important, we will take this method up first.

The Advantages and Disadvantages of Cold Pouring.—Cold pouring has the following advantages:

(1) Cold pouring favors quick solidification in the mold; with a thick crust of solidified metal against the walls; this crust tending to prevent cracking. It may be said therefore, that cold pouring prevents cracking. This, the principal advantage, is sufficient to cause the maker to favor this method.

(2) Cold pouring tends to shorten the pipe. The metal in the molds is comparatively cold, that in the ladle being constantly fed into the mold is much hotter, as the larger body of metal in the ladle will cool much more slowly than the small body of metal in the mold. Consequently, the hotter metal being fed down into the mold immediately fills any pipe. This advantage is, of course, enhanced when large sink heads are used on the molds.

(3) Cold pouring, in causing almost abrupt solidification, especially near the walls, tends to reduce and partially eliminate the large crystal structure often met with in ingots and known as ingotism.

Opposed to these advantages are two disadvantages, both important:

(1) Steel poured cold is not all liquid. It is an emulsion of semi-solid steel in liquid steel, as part of the metal is at or slightly below its solidification point. Obviously in a thick fluid any slag inclusions, gas bubbles and other foreign substances would rise to the top with difficulty if at all.

(2) When the ingots are top poured, if the metal is too cold, small particles splashing against the cold walls will instantly freeze; if the added molten metal is not hot enough to melt these frozen particles, we have a spot or bead on the ingot surface known as a scab or cold shut.

Summing up cold-pouring practice, we may say that this procedure prevents cracking, aids in eliminating pipe and reduces ingotism.¹ Opposed to these advantages, it favors the retention of inclusions and gas, and results in a bad surface on the ingot. The advantage of reducing pipe may not be evident if the ingots are bottom poured, in fact, to pour the ingots from the bottom with

¹ Cold pouring is said to reduce the amount of flake in nickel steels.

cold metal favors the formation of secondary pipe and a resulting scrapped ingot.

The Advantages and Disadvantages of Hot Pouring.—The advantages of hot pouring are almost the converse of cold pouring. As soon as the molten metal strikes the mold, the part in contact with the walls immediately solidifies. Thus a thin skin of solid metal is formed, which as it thickens, contracts in cooling. Continued pouring adds more very hot metal to the top of the ingot which presses down on the still molten interior near the bottom, and exerts a heavy pressure known as ferrostatic pressure. This pressure caused by the weight of the molten metal above on the molten interior below and exerted radially on the thin solidified skin often causes rupture of this contracting skin and results in a crack. Cracking is the chief disadvantage of hot pouring.

The principal advantage of hot pouring is that, due to the metal remaining molten longer in the mold, more opportunity is granted for the solid non-metallic inclusions and gas to rise to the top. This advantage may be worthy of attention in the case of open-hearth steel, but with electric steel, it admits poor furnace practice, as the furnace is the proper place to cleanse the metal, not the molds.

The relative advantages of hot and cold pouring may now be summarized in a very few words. Cold pouring is undoubtedly the best. It insures freedom from cracks and produces a limited amount of ingotism and a smaller pipe, while hot pouring favors cracking, possibly favors piping and certainly favors ingotism. For the reasons summarized here, cold pouring is practiced universally in the manufacture of high-grade steels in this country.

Rate of Pouring.—Fast and slow pouring both have their advantages. Slow pouring is probably better in most cases than fast, although in some grades of steel which are poured very cold a large nozzle and fast pouring are necessary to prevent a frozen stopper or an excessive ladle skull. Too fast pouring will favor cracking; this is enhanced by hot pouring. Slow pouring tends to reduce the pipe. This in a large measure is enhanced by cold pouring. In general, it may be said that in the best practice the metal should be poured cold and as slowly as conditions will permit, remembering that the fast pouring of very cold steel is the equivalent of the slow pouring of hotter steel.

In any case, pouring should be steady; "stop pours" are invariably productive of bad results, especially when the heat is on the cold side. It occasionally happens when pouring cold, if the ladle is shut off momentarily, the upper surface of the metal may freeze where it is in contact with the mold and due to the metal not being sufficiently hot to melt it when pouring is resumed, will form a spot or cold shut on the surface of the ingot. Stop pours are nearly always productive of a bad surface on the ingot. Stop pouring is sometimes practical with hot steel; the ingot including the sink head is filled, after pouring the next ingot the ladle is brought back and more metal added to the one poured just previously. The bad results of stop-pouring are evident only in the body of the ingot, not in the case of the sink head.

CHAPTER XII

THE CHARACTERISTICS OF BASIC ELECTRIC STEEL

The Chemical Composition of Electric Steel—Non-metallic Impurities in Electric Steel—Gas in Electric Steel.

In the foregoing chapters we have discussed at length the manufacture of basic electric steel beginning with the raw materials and ending with the pouring of the ingots. It is desirable that in closing our discussion of basic practice we view some of the characteristics of electric steel and note wherein this grade of material differs from the more common grades made by the Bessemer and open-hearth processes. The basic electric process is unique in two respects: (1) Complete control of sulphur and phosphorus and (2) production of a material free from solid non-metallic inclusions and occluded or dissolved gases.

Electric steel has made an enviable reputation for itself, perhaps not so good as those interested in high grade steel desire, but good enough to satisfy even the most doubtful critic of the virtues and superior characteristics of this product. Electric melting is so new as yet, so untried and so experimental, that nothing but progress can be expected. Its progress in the past few years has been phenomenal as far as installations of new units is concerned; perhaps it has advanced too fast for its own good, but the fact remains, the steel-consuming industries are slowly but steadily and surely demanding that better steels of lighter section replace the ones now accepted as standard. This is especially true in the automotive industry. Motor cars are already becoming lighter in weight but with no sacrifice of quality and strength. This is due to using a better grade of steel throughout the industry. Alloy steel has marked an epoch in the advance of ferro-metallurgical products. But alloy steel is not of first importance. The prime essential in steel is cleanliness. When steel is made clean and kept clean and uniform, then will those sudden and inexplicable failures, now causing so much concern to users of the best steels, cease. Then will the real quality of the metal become apparent, then will the user know he can depend upon the steel

he puts into his product, and then will exhaustive service tests and expensive metallurgical investigation and testing, now made on steels destined for fine motor cars, be no longer necessary.

The U. S. Government proved more conclusively than has ever been proved before how cleanliness improves the properties of steel. Tests made over a period of a year at the Ordnance Plant showed conclusively that electric ordnance steels containing less than .50 per cent nickel, in other words with nickel present only as an impurity and not added intentionally, were equal in every case, and superior in a number of cases, to ordnance steel of the same composition made in the acid open hearth and containing 3 per cent of nickel. What better proof of the superiority of clean steel over the common grades could be desired? And metallurgists admit that the acid open hearth produces the finest steel of any oxidation process. In this connection, it might be said with all fairness that much better electric steel could be made than was produced at that plant. This was due principally to the unfamiliarity of furnacemen with electric furnaces of such large capacity, and through attempting to make 100-ton heats in two 30-ton furnaces. The first 100-ton electric heat had to be made sometime, and the United States Navy is to be complimented that it was the first to take this important step.

It is desirable in our summary that first we look for a moment at the chemical composition.

THE CHEMICAL COMPOSITION OF ELECTRIC STEEL

The electric furnace has gained wide renown in steel metallurgy as the only steel-making medium in which both dephosphorization and desulphurization are possible. This is a feature of the basic electric process the value of which should not be underestimated. But the power of the process to control and eliminate these two impurities has given rise to wide misapprehension; has resulted in many furnacemen thinking that the function of the basic electric process is to dephosphorize and desulphurize and this only; and has caused many engineers and purchasing agents to consider that all electric steel is low in both sulphur and phosphorus; to specify low sulphur and phosphorus, each commonly below .025 per cent; and to consider the amount of these two impurities as paramount in the quality of the material. This is fundamentally wrong. Low sulphur and low phosphorus are

very desirable, but a small amount of these elements is not the only desideratum, in fact, low phosphorus and low sulphur are of minor importance compared with deoxidation and cleanliness. We will consider these points more in detail.

Amount of Phosphorus in Electric Steel.—To remove phosphorus we must oxidize. This means that unless the furnaceman is very expert an excess of oxides above that necessary to remove the phosphorus is at the same time introduced into the bath. It is almost universal for customers to specify that electric steel shall be below .030 per cent of this element, probably 95 per cent of them require that .025 per cent be the maximum and a large number, considerably more than half, will not permit more than .020 per cent. The electric furnace plant is often called upon to make steel containing less than .015 per cent and sometimes even less than .010 per cent. Removing this element below .015¹ per cent presents no difficulty, every furnace plant cheerfully accepting orders with a maximum of .020 per cent specified. A few shovelfuls of ore and the trick is done, unless the scrap is very high in this element when more care must be used. Now when we oxidize strongly, we increase the difficulty of deoxidizing therefore when we overoxidize we take chances on imperfect deoxidation and a resulting unsound steel. It is admittedly much more difficult to deoxidize an overoxidized bath than one which was melted with partial or practically no oxidation. Theoretically this should not be the case but practically it is; whether a modification of the laws of mass action or equilibrium enter into this question we cannot say but in nearly every instance we can melt with ore, deoxidize by a slag high in calcium carbide and containing not more than a trace of ferrous oxide and still have a less sound product than if we restricted oxidation and deoxidized by the same slag in the same way. A strongly deoxidizing slag accompanied by such deoxidizers as manganese, and silicon, even aluminum and titanium will not result in a steel as sound and clean as if the scrap was melted with a restricted supply of oxygen.

Advantages of a Higher Phosphorus Limit for Electric Steel.—The point we wish to make is this: When the furnace plant accepts orders for steel containing less than .020 per cent phosphorus it must sometimes take drastic measures (an excess of ore for

¹ The metal after melting must contain less than .015 per cent phosphorus if a percentage less than .020 per cent is required in the finished steel.

example) to reduce this element to below .015 per cent which is necessary if the finished steel is to be within the limit imposed. The result is only a fair, sometimes only a passable product as far as soundness is concerned. This is the first argument for higher limits in phosphorus.

The next point is one of economy as well as quality. The electric furnace is primarily a reducing medium; oxidizing is, even under the best conditions, costly and in many cases not satisfactory. We have other processes that will oxidize just as completely and much more economically than the electric furnace. When the electric furnace must do the melting, as is the case with most small units, if we can melt with little or no oxidation, we can melt faster, we do not need to spend the time necessary to slag off completely or in many cases use two oxidizing slags, and we can deoxidize quickly and completely. We have viewed this practice at length in a previous chapter as melting without oxidation and melting with partial oxidation. Now, admitting that melting without, or at most with very little oxidation, is the best and most economical practice, increasing the permissible limits for phosphorus to .040 per cent or even .030 per cent especially for the tool steels and other special grades would increase the available supply of scrap for this melting practice many hundred per cent, and make it a daily procedure instead of one carried out occasionally. Scrap dealers can furnish a practically unlimited amount of scrap guaranteed to be below .040 per cent. On the contrary they have none which is guaranteed to be below .020 per cent. Even with an upper limit of .030 per cent scrap would be available in large amounts, as practically all low carbon basic open-hearth steel is below this figure and basic open-hearth steel goes into rather well-defined products from which ample scrap is available.

Electric steel melted without oxidation is, in practically every case, superior to that made with any other electric melting practice. Not only that but it is also cheaper. If scrap was available, and there would be plenty if the phosphorus limits were raised, the general quality of electric steel made from an all-scrap base should increase to a marked degree.

Let us look at the hot metal process for a moment. It is here that the great expansion of electric steel in the future should occur. If higher phosphorus were permitted in the electric furnace, the open-hearth melter supplying the hot metal would not be com-

pelled to oxidize so completely. He could conveniently remove his carbon, manganese and phosphorus in the usual manner, and could partially deoxidize his metal just before tap with 10 per cent ferro silicon in the furnace or while tapping with the 50 per cent alloy in the ladle and would not have to worry about a small amount of possible rephosphorization caused by this deoxidizing alloy.

Disadvantages of a Higher Phosphorus Limit.—There is considerable doubt in the minds of many metallurgists whether phosphorus does any harm at all in amounts below .040 per cent. If this is the case, there is no difference in cleanliness, soundness and quality as far as this element is concerned in steels containing .039 per cent, .029 per cent, .019 per cent and .009 per cent respectively. Lest it should be misunderstood, it should be noted that in the basic electric steel industry "high" phosphorus is one exceeding .030 per cent. Phosphorus percentages of more than .040 are practically unknown in basic practice. Therefore we call .030 to .040 per cent high phosphorus, .015 to .025 per cent normal phosphorus and below .015 per cent low phosphorus.

Ghosts and banded structure have been laid at the door of phosphorus; perhaps wrongly, surely with too much certainty in view of the present known facts. Recent investigators have shown, probably conclusively, that solid non-metallic inclusions in the ferrite lines are responsible. If more attention were paid to the presence and possible harm of included ferrous oxide, silicates of various compositions and a number of gases instead of phosphorus better steel would doubtless be made. Steel makers and steel users are too much bound by precedent. Many years ago, phosphorus was found to cause cold shortness. The maker has been struggling against and the user has been avoiding the element ever since. It is true that phosphorus is harmful in appreciable amounts but can we call a percentage of .040 per cent or below appreciable? Then again, a reason for the apparent importance of phosphorus is the fact that it can be determined with great accuracy by chemical analysis while oxides, silicates and gases cannot. Acid open-hearth steel always contains more phosphorus, often three times as much as basic open hearth. Acid open hearth is admittedly much better than basic open hearth (see p. 16). Why? Because it is more thoroughly deoxidized than the basic product. If phosphorus were a measure of quality the acid open hearth would not now be the acknowledged

medium for the manufacture of ordnance steels, in fact the acid process would not have survived.

The Amount of Sulphur in Electric Steel.—Sulphur is the element that worries the electric steel maker the least. When his deoxidizing slag is functioning properly, desulphurization is automatic and complete. Unless unusual conditions are present, high sulphur in the scrap or in the slag-making materials, the percentage of this element in the finished product is nearly always below .025 per cent, usually below .020 per cent and often below .015 per cent. These percentages, obtained easily and as a natural sequence to deoxidation, represent a harmless amount. Above .025 per cent sulphur the amount of manganese sulphide begins to be noticeable in a photomicrograph of the metal although it may be harmlessly distributed even when as much as .050 per cent is present. Sulphur is never as harmless in small amounts as phosphorus; the latter dissolves in the ferrite as iron phosphide, Fe_3P , but the former, as manganese sulphide, MnS , is insoluble and appears as rounded areas or elongated fibres in the metal, sometimes in the grains, often at the grain boundaries. Because manganese sulphide is present as an inclusion, and because inclusions are harmful as breaking up the continuity of the metal, it follows then that sulphur in any amount is undesirable, much more undesirable than phosphorus which in small amounts is in solution in the ferrite. Sulphur can be eliminated with little trouble in the basic electric furnace. This removal is, as we have seen, practically automatic. Therefore an increase in the allowable limits of this element is not so important as in the case of phosphorus, although it is probable that steel containing .030 per cent sulphur is of exactly as good quality, as far as this element is concerned, as one with .020 per cent. It would be unnecessary and would perhaps result in too much manganese sulphide which might possibly cause harm, if limits higher than .030 per cent were permitted.

Other Elements in Electric Steel.—There is very little concerning the other elements in electric steel that needs any discussion in addition to what has been said in the chapters on the melting practice. All of the common constituents except nickel and copper are under the melter's control. The danger of nickel in tool steel has already been noted. Copper like nickel cannot be removed when once in the metal. This element has long been considered harmful to steel; during the war the Government

prohibited more than .20 per cent copper in some of their ordnance steels. Recently the experiments of the U. S. Navy with copper gun steels have dealt a death blow to the fallacy that this element is harmful. Evidently the harm in copper came from the formation of copper sulphide. Probably this constituent would cause hot shortness as easily as iron sulphide. If an excess of manganese is present to insure that all of the sulphur exists as manganese sulphide, no copper sulphide could exist. This is particularly true with electric steels where the amount of sulphur is so low and the amount of manganese is so many times that necessary to combine with all of the sulphur. The copper steels made at the Ordnance Plant and containing .50 per cent and 1.00 per cent of this element gave no evidences of being hot short.

NON-METALLIC IMPURITIES IN ELECTRIC STEEL

The non-metallic impurities possibly present in electric steel are of five classes, of which the first two are the most important. They are:

- (1) Products from the reaction between dissolved and suspended oxides and gases and deoxidizers.
- (2) Oxides, not acted on by deoxidizers.
- (3) Oxides from the oxidation of the metal in tapping and pouring.
- (4) Mechanically mixed slag.
- (5) Dirt from ladle bricks, molds, runners and other sources, foreign to the furnace, and picked up by the metal through contact.

Any or all of these five classes may be present. Concerning their importance the first is the source of most of the inclusions found in electric steel. The second class should not be present at all but sometimes is present and may cause much harm, in fact a small amount of ferrous oxide is probably present in all electric steel melted with complete oxidation. In tapping the heat and in pouring the ingots the metal in passing through the air may become oxidized to a greater or less extent. The possibility of contamination by oxides in this third class is present in all grades of steel and cannot be easily prevented. The oxidation here is not great in amount. The introduction of mixed slag noted in the fourth class can, to a large measure, be prevented and is prevented in good practice. Mechanically

mixed or entrapped dirt picked up from spout, ladle lining and from the interior of molds is insignificant. All furnacemen use care in keeping ladle and molds clean so the chances of the metal picking up dirt are reduced to a minimum. In addition most of the foreign material accidentally entrapped is of a size sufficiently large to rise to the top by gravity.

Inclusions from Reaction Products.—We have noted in a previous chapter (p. 170) where the chemistry of deoxidation was discussed, why electric steel should be free from inclusions resulting from reaction products. If the slag is strongly carbide, ferrous oxide and manganese oxide cannot exist in it in appreciable amounts; and through migration from metal to slag, and by gravity, the metal likewise should be free from oxides and from silicates of iron and manganese. This is never wholly true, although in the electric process conditions are ideal for a complete elimination of these impurities. If the silicates succeed in coalescing completely into particles large enough to be influenced by gravity and not held by mass action, the steel will be completely free unless more inclusions are introduced at a late period in the process when insufficient time is available for these to leave the bath.

In melting with partial or restricted oxidation, the manganese addition and 1 hr. under the carbide slag are sufficient to eliminate dissolved ferrous oxide almost completely. Then when ferrosilicon is added late in the heat, there will be no solid oxide in the bath available for the formation of silicates of iron and manganese. The resulting steel should be free from these inclusions. Now, if the melting is with complete oxidation, a large excess of ferrous oxide will be dissolved in the bath. Neither the manganese addition nor the carbide slag will eliminate this dissolved impurity completely because the greater the excess the more difficult the removal of the final traces, and the more time necessary to accomplish this removal. When the final addition of silicon is made, this more energetic deoxidizer will react with these last traces of ferrous oxide and with some manganese to form the regular compound slag-forming silicates. At this stage too little time is available for complete coalescing and elimination, and consequently, the steel will contain a few silicate slag inclusions.

With well deoxidized electric steel melted with care, and deoxidized by a strongly carbide slag, non-metallic inclusions

as represented by silicate reaction products should be completely or very nearly completely absent.

Manganese sulphide, MnS , is the other reaction product with which the maker of electric steel must contend. It is present in the scrap as manganese sulphide, occasionally with much sulphur as iron sulphide, FeS ; and will be retained by the bath after melting as the former, perhaps the latter constituent. Ferrous sulphide is rare and will be completely superseded by manganese sulphide as soon as the manganese addition is made. All of the sulphur not removed by the carbide slag as calcium sulphide will be found in finished steel as gray areas of manganese sulphide, rounded in cast steel or in the transverse section or elongated into fibres in the longitudinal section. If the electric furnace final slag removes all but .020 per cent sulphur, only .050 per cent manganese sulphide will be present and usually so well distributed as to be practically harmless.

Summing up, we say that electric steel will contain a small amount of finely dispersed manganese sulphide, so little as to be practically harmless and if proper care is used in the refining, a negligible amount of silicates.

Inclusions of Oxides.—The possible inclusions from oxides include ferrous oxide not acted on by deoxidizers and silica entrapped and not forming fusible silicates. In addition, the metal may contain carbon monoxide which being a gas will be more properly discussed in the next section. Theoretically, basic electric steel should contain no dissolved ferrous oxide, practically, however, in electric steel melted with complete oxidation it is probable that it does contain some. This whole question is exceedingly uncertain and complex, therefore any statement made must necessarily be in the nature of a conjecture. This much is certain however, considerable ferrous oxide escaping reduction is present in Bessemer and some grades of open-hearth steel. If a part of this oxide escapes reduction in these two processes due to mass action, lag in the completion of reactions and for other reasons we may without possibility of contradiction assume that some, though a very much smaller amount, escapes reduction in electric steel in which oxidation with ore was practiced. We have no way of determining accurately how much ferrous oxide actually exists in steel and because chemical analysis falls short in this respect, we are too often ready to ignore what we cannot determine with certainty. At least

two authorities, probably more, have stated that hot shortness may be caused as easily by dissolved ferrous oxide as by sulphur.

In the case of ferrous oxide in electric steel, we know that we can remove most of this constituent from the final slag by calcium carbide and we know that the ferrous oxide in metal and slag tends to establish a state of equilibrium. We also know with certainty that no matter how reducing we make our slag, we always find at least traces of ferrous oxide present. It follows therefore, that there will be a very small amount present in the molten bath. This amount may be called negligible, probably it is after being acted upon by calcium carbide, carbon, manganese and silicon; however, we do not know just how harmless or otherwise even an exceedingly minute trace of this oxide may be.

We have already seen that it is desirable to add at least part of the silicon used for degasifying about three quarters of an hour or more before tap. This is to accomplish the deoxidizing of any carbon monoxide early so the resulting reaction product, silica, will have time to leave the steel. When we add silicon, we have little if any manganese or ferrous oxide present in the bath, therefore conditions are not favorable for the formation of easily fusible silicates that coalesce and rise quickly through gravity. Instead, the reaction product silica, SiO_2 , is solid at steel-making temperatures and tends to remain emulsified and entrapped in the metal, rising to the top only if a considerable period of time is allowed. It has been found by experience that the early addition of silicon produces a more completely deoxidized and sound product than when this alloy is added just a few minutes before tap.

Therefore, as far as included oxides are concerned, basic electric steel should be free or very nearly free from ferrous and manganese oxide, and if the silicon is added early and into a hot bath, should contain only a small amount of occluded silica. In addition, the traces of this constituent should be so well dispersed as to be harmless.

Oxidation of the Metal in Tapping and Pouring.—It is certain that some ferrous oxide is formed by the oxidation of the metal in passing from furnace to ladle and from ladle to mold. With present methods of steel manufacture, the oxidation that occurs here cannot be eliminated nor even controlled. We have no way of knowing how much oxidation happens here, but it cannot

be appreciable as in practically every instance the quality of the ingots is determined by the history of melting and refining. Although we say this advisedly, realizing that the influence of ferrous oxide on the final qualities of steel is a matter about which very little is known, it has been the experience of most metallurgists that when a blowy or dirty electric steel heat is made, the poor qualities can usually be traced to the furnace practice.

Like the ferrous oxide that may remain in the metal after deoxidation, as noted on a previous page, any ferrous oxide from oxidation by the air in tapping or teeming will dissolve in the molten metal and while it may remain in the solid steel as the oxide, it may also be reduced by any carbon,¹ with which it comes into contact, forming carbon monoxide gas. The blue flames seen darting from the top of the ladle slag in an electric heat are the result of carbon monoxide burning to carbon dioxide. As these flames appear to a slight extent even in well deoxidized and degasified steel, steel on which the heat test poured solid and free from blow-holes, they are probably the result, partly at least, of ferrous oxide introduced into the metal in tapping with later reduction by the carbon. Therefore, concerning the oxidation of the metal in tapping and pouring, it is certain that some takes place; it is probable though, that what does occur is not of great importance in determining final quality. This oxidation is not easily preventable and so must be accepted as a necessary evil. The oxidation here is probably of such slight influence on the final quality of the steel that it may be ignored.

Mechanically Mixed Slag.—Electric steel makers, when using the old style furnaces, have been troubled with occasional slag patches in the steel. This was due principally to the intermixing of slag and metal in the ladle. We have discussed this before and have seen that on furnaces of recent construction, a special door or a skim gate is used to separate metal from slag and to tap the former completely before the latter. When metal and slag are mixed together, the violent churning taking place in the ladle is sufficient to break up some of the slag in particles fine enough to be retained in the body of the metal.

The slag in the basic process is so high in bases and has so little surface tension that it breaks up readily and mixes inti-

¹ It may also be reduced by any manganese or silicon with which it comes into contact.

mately with the metal. The slag from an acid process on the contrary has much greater surface tension and therefore does not break up readily. This is one reason why crucible steel is so free from slag spots and why electric steel will have slag spots if metal and slag are tapped together. As now made, in the greater majority of shops, electric steel should be free from non-metallic impurities introduced through the mixing of metal and slag.

Dirt and Other Foreign Inclusions in Electric Steel.—We have noted, in a previous chapter, that electric steel should be tapped into a ladle containing no slurry or wash and that the sand used for testing the nozzle should be blown out before the ladle is used. In other words, the ladle should be perfectly clean. This is now watched in practically every shop. In addition the molds should be clean. In many plants they are kept covered and as an extra precaution are blown out with compressed air just before the heat is teemed. This applies to top pouring. It is more common in bottom pouring to find occasional ingots that are dirty as keeping the molds and runners absolutely clean requires considerable care.

In general, extraneous dirt and other foreign substances introduced into the metal from ladle and molds is nearly always due to carelessness and is consequently readily preventable.

Summary.—We may summarize briefly. It may be said that electric steel should be practically free from solid non-metallic inclusions because:

(1) Reaction products such as iron and manganese silicates resulting from deoxidizing reactions cannot be present in appreciable amounts.

(2) The reaction products that are present have time allowed for them to leave the steel.

(3) Except the extremely minute amount of ferrous oxide held by mass action this constituent should be absent. This small amount will depend upon the melting practice used. In melting with complete oxidation the dissolved ferrous oxide may be sufficient to affect the physical properties slightly; if on the other hand the heat is melted without oxidation, the amount should be infinitesimal.

(4) There will be a small amount of occluded silica present depending upon the amount of gas in the bath and the time of adding the ferro-silicon. This solid non-metallic inclusion should

be highly dispersed and, in the amount possible in good electric steel, harmless.

(5) All of the sulphur will be present as manganese sulphide. This impurity is never great in amount as the natural deoxidation eliminates sulphur almost completely. In most cases, the amount of MnS may be called negligible.

(6) A small amount of oxidation due to the passage of the metal through the air in tapping or pouring may occur. It is slight and has but little influence on the properties of the steel. This oxidation probably results in the formation of a small amount of carbon monoxide gas.

(7) When precautions are taken to hold back the slag in tapping, none should become mechanically mixed with the steel.

(8) In good practice, there is no opportunity for extraneous dirt and foreign matter to be present in the metal.

We see therefore, that except for a small amount of manganese sulphide and possible traces of silica, electric steel should be free from non-metallic inclusions when melted with restricted or with no oxidation. Even when melted with complete oxidation, if it is deoxidized thoroughly, it should be much cleaner than basic open hearth and very much cleaner than Bessemer.

GAS IN ELECTRIC STEEL

One of the principal reasons for the superiority of electric steel over open-hearth and Bessemer metal lies in its comparative freedom from gas. For sometime it has been suspected that gas may be present and have an extremely deleterious effect on steel. Recently a large number of investigators have shown that molten steel may dissolve or absorb appreciable quantities of hydrogen, carbon monoxide and nitrogen. One of the great difficulties encountered in investigating gas in steel is that chemical analysis is practically helpless in determining the amount present, and the microscope is but little better. One or two investigators, however, have shown that some gases predominate and that these gases may have a remarkable effect on the physical properties.

Amount of Gas in Steel.—Due to a comparatively recent research we have gained an approximate idea of the amount of gas that may be present. Two German investigators¹ showed that on a very large number of open-hearth steels, the gas dissolved was 13 to 130 cc. per 100 gm. of metal. This is equal, taking the

¹ OBERHOFFER and BEUTELL, *Stahl und Eisen*, 39, pp. 1534–90, 1919.

lowest figure, to more than 130,000 cc. per ton or for a 10-ton ingot 1,300 liters. These figures give some idea of the amount of gas that may be dissolved or occluded in apparently sound metal. The investigators, in analyzing the gas, found that it averaged about 75 per cent carbon monoxide; the rest was hydrogen, nitrogen and a small amount of carbon dioxide. If good open hearth steel will contain from 130 to 1,300 liters of gas per ton, it is to be expected that this gas will have some influence on the physical properties. Therefore from the above figures, it is quite evident that steel metallurgists have paid far too little attention to the presence of gas in steel and to its effect on the final quality.

The gas that has received more study than any other is nitrogen. It has been proved without possible doubt that nitrogen reduces the tensile strength and greatly reduces the ductility. This is due to the brittleness of iron nitride. It is in the reduction of the nitrogen content that ferrotitanium has become so important.

Amount of Gas in Electric Steel.—Let us compare for a moment the relative amounts of gas in basic open-hearth and basic electric steel. In the open-hearth process we have an oxidizing atmosphere in the furnace due to the nature of the heat (producer gas, oil etc. and air). With these hot gases, are introduced large volumes of nitrogen and some hydrogen from the dissociation of water vapor in the air. From the oxidation of the carbon we have carbon monoxide. Therefore the bath in the open-hearth process may contain oxygen, nitrogen, hydrogen and carbon monoxide.

Now in the electric process, we have no atmospheric oxygen introduced (except a little that may leak in around the doors and which is negligible). Consequently no oxygen, hydrogen nor nitrogen can possibly be present in the metal,¹ after melting is complete. It is at once evident, that here electric steel is superior to either open-hearth or Bessemer.

Carbon monoxide is the only gas that may be present. This gas caused by the oxidation of the carbon by ferrous oxide is present in an amount depending on how far oxidation was carried. It follows therefore that when the heat was melted with complete

¹ This is true in the cold-scrap process. When molten open-hearth metal is refined a little oxygen, nitrogen and hydrogen may be introduced into the electric furnace with the hot metal. The whole deoxidation period is then available for this to be eliminated.

oxidation there will be much more CO present than when oxidation was restricted. But even with complete oxidation we do not have the condition that is present in the open hearth, especially in the pig and ore process where a very large excess of oxygen is introduced. Besides, we never have the oxygen in the furnace gases. Consequently, in the electric furnace even under the strongest oxidizing conditions, carbon monoxide will be much less in amount than in the open hearth and in addition nitrogen, hydrogen and oxygen will be completely absent.

We have already noted in detail the process of degasification whereby the dissolved carbon monoxide that has persisted to the end of the refining is reduced by silicon and thus eliminated. The result is that with care in melting and refining, electric steel should never be blowy, but should on the contrary be very sound and free from gas cavities. So, except for a little carbon monoxide introduced through the interaction of FeO and C after the heat is tapped, and this should be negligible, it follows that blowy electric steel is the result of the poorest furnace practice.

The Acid Test for Degassed Steel.—The amount of gases (perhaps of oxides as well) in steel has a direct influence on the solubility of the metal in dilute acids. In fact it is possible to classify steels approximately as this method is a direct measure of the density of the metal. The test is only applicable to steels containing no alloys or at most but small amounts. The test in brief is as follows: 5 gm. of the sifted drillings (through 20 mesh and on 40 mesh) are placed in a beaker and 100 cc. of dilute hydrochloric acid (one part acid, one part water) added. Bessemer steel dissolves in a few minutes, 5 to 10, when gentle heat is applied. Basic open-hearth steel takes 15 to 20 min. or twice as long and electric and crucible steels, the two most perfectly deoxidized metals, will not be dissolved completely in less than 30 min. often taking 45 min. to 1 hr. for solution to be completely effected. In making this test it is essential, for comparative purposes, that the steels be in the same condition; annealed or air cooled, for example. The solubility test is therefore a direct indication of the quality of the metal.

The conclusion drawn from the solubility test is:

- (1) Bessemer steel is the most unsound of the three varieties noted above.
- (2) Basic open-hearth steel occupies a place midway between Bessemer and electric.

(3) Electric and crucible steels have the slowest rate of solution. The cohesion between the grains or molecular masses as the case may be is the greatest in these steels. This higher cohesion is caused by absence of gases or oxidation defects. The above facts are self-evident and need no further discussion.

Conclusion.—In concluding, we may, in a short statement, sum up all we have learned about the manufacture of electric steel by the basic process.

(1) Electric steel can be made in any unit from a few hundred pounds to 100 tons, can be made nearly free from sulphur and phosphorus if desired, and can be made to an exact analysis. Because all alloying additions are made to the furnace, it will be uniform in composition and because of the reducing conditions present there will be no loss of alloys.

(2) Because of the flexibility of the process and due to the heat which is not oxidizing, as is the case with the Bessemer and open-hearth, oxidation may be controlled; the melting may be with complete oxidation, with partial oxidation or with no oxidation. Deoxidation can be made very complete in all cases. Due to the efficiency of the deoxidizing reactions, the absence of appreciable amounts of solid non-metallic inclusions in the finished steel may be assured. Due to the nature of the heat, the absence of air and the efficiency of silicon in eliminating carbon monoxide, the absence of dissolved or occluded gases may also be assured.

Therefore, steel of the highest quality can be made by the basic electric process in heats of any size up to 100 tons.

CHAPTER XIII

ACID-MELTING PRACTICE

General Features of the Acid Process—Melting and Refining—Chemistry of the Acid Process—Acid versus Basic Electric Steel.

In the past few years the manufacture of electric steel in acid-lined furnaces has increased greatly; increased to such an extent that at present about half of the total production of steel castings, in fact nearly all of the small castings production is the result of the acid process. While not adapted to ingot manufacture and possessing too many inherent disadvantages to be used for this product in furnaces of 6 tons and larger, it has gained a wide following in castings production for which it possesses too many advantages to be completely supplanted by basic practice.

Theoretically the acid process cannot produce as good steel as the basic. Practically, however, exceptionally good material has been made in acid-lined furnaces, as good, or even better in some cases, than some basic electric steel. This is due to two things: (1) The high surface tension of the acid slag tends to prevent slag emulsification and a large number of resulting inclusions; and (2) acid furnaces are nearly always small in size, are operated in most instances independent of other melting operations and are, in the majority of shops, in charge of men understanding their operation and interested primarily in producing a high-grade product. In castings production the electric furnace has, in many cases, supplanted the crucible and Bessemer process; supplanted the crucible because it is more flexible and because higher temperatures and a more fluid steel can be obtained; and supplanted the Bessemer converter because the product is more sound, more uniform and higher grade.

Another advantage of the acid process is the continued silicon reduction going on through the latter part of the refining period. The silicon reduced from the silica in the slag migrates into the metal and by means of its great affinity for oxygen produces a continued degasification and deoxidation all through

the latter part of the process. This feature of acid practice is the cause of some dispute among metallurgists; some hold that the reduction of silica to silicon is of great benefit to the metal; others on the contrary belittle the deoxidation and degasification accomplished by this element, maintaining that the benefits are of doubtful value. We shall have occasion to refer to this again in a latter section.

Acid electric furnace practice received a great impetus during the war when numerous foundries after installing electric furnaces found that they could not obtain magnesite except at a prohibitive cost; in fact some of them could not get this basic refractory at any price. Thus they lined their furnaces with acid material and produced their castings by the acid process. They found that, on the whole, it was so satisfactory especially in the production of small work (200 lb. and less) that even when basic refractories became cheaper and easier to secure, they refused to change to the basic process. As a result several prominent foundries are at present producing very high-grade castings in acid-lined furnaces.

GENERAL FEATURES OF THE ACID PROCESS

In the acid electric process the whole lining, including the bottom and lower side walls is acid material. The scrap is melted in the usual way, the carbon, manganese and silicon are oxidized wholly or in part during or just after melting. The rust and dirt on the scrap together with the silicious material worn or dislodged from bottom and banks forms the slag. The carbon, if too high, is lowered by successive small additions of iron ore until the proper percentage is reached after which the metal is deoxidized as much as possible in the furnace and the temperature adjusted. Ferromanganese together with ferro-silicon if necessary is added, the ladle is placed in position, and the heat tapped.

In viewing the general features of the acid process preliminary to a discussion of melting and refining three divisions naturally present themselves: (1) The furnace, (2) the lining, roof and bottom and (3) the scrap used.

The Furnace.—As before noted the acid process is used primarily for castings; it is of great importance in the production of small castings; consequently the furnaces are nearly always of small size. The most common capacity is 3 tons;

furnaces of 1 and 2 tons sometimes being used. The larger cold-scrap furnaces so common in the production of basic ingots, 6 to 8 tons, are not favored by many foundry operators.

Most acid furnaces are overcharged. By constructing a cup-shaped hearth the furnace can easily hold at least 50 per cent overload. Thus it is common to tap 8,000 to 10,000 lb. from a 3-ton furnace.

Most of the furnaces working on acid castings are Heroult or furnaces of the Heroult type, *i.e.* direct, series arc with a non-conducting hearth. The keen competition in the manufacture of castings makes it necessary to operate each furnace as rapidly and economically as possible. In addition, many castings plants operate days only. The direct arc furnace is admirably suited for both of the above essentials.

The Lining and Roof.—The lining and roof are of silica brick; the bottom is of silica brick and silica sand. The brickwork of the walls, like the 6-ton basic furnace described in Chapter IV, is commonly $13\frac{1}{2}$ in. thick and is composed of one course of silica straights laid flat and parallel to the furnace shell¹ and one course of silica headers. In some furnaces a 9-in. wall is used. The brickwork of the acid furnace is laid with a thin mortar of fireclay, just enough being used to fill up any crevices or irregularities in the brick. Expansion joints of thin lath or cardboard are put into a new lining at frequent intervals as silica brick expands appreciably when the furnace is first heated.

Roofs are constructed similarly to those used on basic furnaces. For the 3-ton most melters prefer standard shapes instead of the special shapes used commonly on the 6-ton Heroult.

Linings and roofs on acid furnaces have a variable life depending almost wholly on operating conditions. The expansion and contraction of silica brick promotes comparatively early failure when the furnace is operated intermittently as is the case in many shops.² Unlike the 6-ton furnace producing basic ingots, and which invariably shuts down but 18 to 24 hr. on Sunday, in many foundries the small acid furnace runs day turn only. This is one cause for earlier failure of the lining. It should not be taken as an accepted fact that the lining and roof of the acid furnace

¹ Firebrick are sometimes used here instead of silica brick.

² Silica brick are likely to crack when subjected to extreme temperature changes. See p. 24.

fail sooner than the lining and roof of the basic furnace. In continuous operation they will both give about the same service, in fact many acid furnaces produce much greater tonnage on a lining and roof than basic furnaces.¹

The Bottom.—Instead of the shallow saucer-shaped hearth common in the larger furnaces, the small furnace usually has a deep cup-shaped bottom. As we stated on a previous page this allows a furnace of given capacity to carry a considerable overload. In addition this arrangement is advantageous in that most of the charge is piled in the center of the furnace, directly beneath the electrodes. The cup-shaped hearth may be used in acid furnace practice as it is not necessary to have so large a plane of contact between slag and metal as in the basic process.

The bottom proper is silica sand. It may be put in by burning or tamping. The fritted bottom is, of course, the best as the sand in each layer is set solid; not just the top 3 to 6 in. as in the tamped hearth.

In building a tamped bottom silica sand and a small amount of fireclay, or ground ganister, silica sand and fireclay are mixed, shoveled into the furnace and tamped in solidly, usually with a foundry air rammer. The furnace is then dried by a wood fire for 24 to 48 hr. After the ashes are dumped, coke or pieces of broken electrodes is distributed over the hearth and the power turned on. The heat is kept low and the power is turned off and on intermittently to avoid overheating the roof and upper side walls. The refractories should be completely set in 8 to 10 hr. The furnace is then ready for the first heat.

The fritted bottom is composed of silica sand containing 4 to 8 per cent iron oxide (Fe_2O_3) or silica sand mixed with a little fireclay. This is shoveled in and fritted to the bottom in layers much the same way as in the basic furnace.

Bottom Repairs.—Repairs are made to the bottom and lower side walls after each heat. For this purpose silica sand or a mixture of ground ganister and silica sand is used. The sand or the mixture is usually dampened a little so it can be placed more accurately with a shovel. Dry sand is placed high up on the side walls with difficulty, as it tends to drift down onto the bottom unless dampened enough to stick. When a heel (see

¹ As there is little if any refining in the acid process it follows that the metal will not be in the furnace any length of time. Therefore the lining should last much longer than with the basic process.

below, is left in the furnace after each heat repairs are made only to the walls. The bottom is taken care of when the furnace is completely emptied after the last heat of the day.

It is necessary to clean all holes in the bottom of metal before making repairs. (This is true of the basic process as well as the acid.) The end of a cold rabble or hooked bar is turned about in the hole until the metal freezes onto it. This is known as "balling out the metal." After making the necessary repairs to the bottom and side walls it is advisable to let the furnace stand empty for a few minutes to permit the added refractories to set firmly into place.

The Scrap.—The scrap used in the acid process does not differ materially from that used in a basic-lined furnace. From 25 to 50 per cent of the charge is often foundry scrap. This is commonly placed on the bottom of the furnace. The balance, which is usually fine scrap, is then placed on top. This latter may be heavy lathe turnings, boiler plate punchings, light plate scrap, light forge flashings, etc. The scrap, as far as possible, is piled in the center of the furnace to avoid too much "pushing in" and should be heavy enough to prevent the electrodes from boring to the bottom too fast.

As is characteristic with acid processes in general, the acid electric process removes neither sulphur nor phosphorus and, as these elements sometimes increase slightly, the average in the charge must be a little below the requirements of the finished steel. Basic open hearth scrap is always satisfactory for the acid process as it is nearly always below .040 per cent and often below .030 per cent in both sulphur and phosphorus. The average foundry scrap will range somewhat higher, probably between .040 and .050 per cent. It is, of course, necessary to attach the proper importance to the percentage of sulphur and phosphorus in the scrap. This subject needs no further discussion as the amount in the finished steel depends wholly on the amount in the charge and is thus beyond the control of the furnaceman.

Some foundries melt an extra large charge for the first heat of the day and leave a few hundred pounds of molten metal in the furnace when each succeeding heat is tapped. This is known as a "heel." When the scrap is charged for the second and ensuing heats this molten metal serves to weld the scrap into a compact mass that offers better contact for melting. Repairs are made to

the furnace above this residual molten metal after each heat. When the last heat of the day is tapped the metal is drained completely from the furnace and the bottom thoroughly repaired.

MELTING AND REFINING

The acid process as practiced in electric furnaces is a one-slag process. Another feature distinguishing it from basic furnace practice is that ordinarily no slag making materials are added to the charge or to the molten bath. The whole slag comes from the impurities either on or contained in the scrap together with the silicious material worn away or detached from bottom and banks.

Melting and refining is rapid, and aside from the characteristics of the slag and chemistry of the process which will be discussed in a later section, is comparatively simple.

The practice may be divided into two periods: (1) Melting and oring down and (2) finishing the heat.

Melting.—Most of the details of charging have been discussed on a previous page. When a good grade of shoveling scrap is used a 3-ton furnace can be charged by hand in 10 to 25 min. Hand charging is nearly always used; there is no advantage in the use of a charging machine for the small furnace. In fact, taking into consideration the space taken up and the additional investment required, it is doubtful whether mechanical charging is practical for a furnace of less than 8 to 10 tons capacity and probably only practical here when four to six furnaces are being operated continually.

After charging is complete the power is thrown on and the scrap melted as rapidly as possible. The time of melting varies from 45 min. to $1\frac{1}{2}$ hr. for a 3-ton furnace, depending upon the design of the furnace, the character and compactness of the charge, and the experience and skill of the furnaceman. Some pushing in is usually necessary, although this job is avoided to some degree by a deep hearth.

Melting should be without excessive oxidation, which may be prevented by using a clean scrap. The principal reason for avoiding excessive oxidation is to secure the benefits of leaving some residual manganese in the bath.

To control oxidation it is essential that successive charges be made up of scrap of about the same size and character. The character of the scrap; that is, the amount of rust and dirt governs to a large extent the amount of oxidation and the result-

slag volume. Clean scrap produces a small amount of slag; conversely, rusty scrap, a large amount of slag. In standardized practice, the slag volume should be kept nearly constant as abrupt changes in this variable necessitate changes in the method of handling the heat.

Refining.—As soon as the bath is melted, the metal is stirred and a test taken. This metal test is broken and the carbon is estimated from the appearance of the fracture. To serve as a check one-half of the test is drilled and analyzed for carbon and manganese by the laboratory.

The metal after melting is completed may be almost free from slag. The slag, however, accumulates rapidly from this point to tap.

If the carbon content has been adjudged to be too high, the melter adds ore to the bath. This he throws into the furnace in small doses, 3 to 6 lb. at a time, waiting for the action produced by one addition to cease before adding another. The melter judges the carbon elimination by fracture tests. When he decides that the percentage is about right he may or may not take out another metal test for analysis. In either case, as soon as the carbon is down to the right point the heat is ready to be finished.

Finishing the Heat.—Finishing an acid heat consists simply of heating the metal up to the desired point, adding ferromanganese, sometimes ferrosilicon as well, and tapping. Electric steel for castings ordinarily contains about .25 per cent carbon. After considerable practice the melter can make the heat without the aid of a laboratory although most foundries now employ a chemist to check their melter's estimate of the carbon percentage.¹ While the melter is waiting for the laboratory to inform him of the carbon percentage in his last test he is heating his bath to the point required for the particular product being made.

It will be noted that here the acid process differs radically from basic practice. In the latter the deoxidation takes place in a hot bath and the last 5 or 10 min. is spent in cooling to tapping temperature. Contrary to this, the furnaceman on an acid furnace avoids a hot bath during refining to prevent excessive

¹ It is much more difficult to "read a fracture" accurately on electric steel than on open-hearth. Electric steel is nearly always more close grained than the fracture of a test piece of the corresponding carbon content from the open-hearth.

silicon reduction and applies additional heat to this metal in the last few minutes.

Tapping the Heat.—Most small heats (3 tons or less) are tapped into lip-pour ladles. These are more economical for foundry use than the bottom-pour ladles used for ingots. By the lip-pour ladle practically all pouring troubles such as leaky stoppers, frozen stoppers, and the like are obviated. In addition, pouring into hand ladles is made easier. The chief objection to the regular bottom-pour ladle is the trouble and care necessary in setting the stopper. It is as much work to set a stopper for a 3-ton ladle as for a 100-ton ladle.

An important objection to the lip-pour ladle is the likelihood of slag getting into a mold, unless carefully held back. This objection would prevent its use in basic practice as the basic slag has so little surface tension and is so easily broken up and dispersed into a finely divided form that a lip-pour ladle would produce a material almost sure to contain slag spots. The acid slag, on the contrary, has a much higher surface tension; it is, therefore, much more difficult to disintegrate and thus emulsify it. A small amount of slag poured into the mold with the metal would, unless entrapped by the mold walls, rise quickly to the top by gravity. It seems unnecessary to state, however, that even though the acid slag has this desirable characteristic, it should be kept out of the mold altogether.

Alloy additions may be made to the furnace either just before tap or to the ladle while tapping. The former is undoubtedly the best. It is customary to add the ferromanganese to the metal in the furnace 5 to 10 min. before tapping. If ferrosilicon is also used the addition of this alloy may either precede or follow the ferromanganese in the furnace¹ or may be thrown in the ladle. Alloys other than these two are not used often. If nickel steel is made the nickel may be added any time during the refining period. Chrome is best added to the metal in the furnace just before tap and after the manganese additions to prevent loss of the alloy by oxidation.

THE CHEMISTRY OF THE ACID PROCESS

It can be inferred from the discussion of melting and refining in the previous section that the chemistry of the process is much

¹ It will be shown in the next section why ferrosilicon should be added before ferromanganese.

simpler than in basic practice. There are but three elements to control, carbon, manganese and silicon, against five in the basic electric process. The two most undesirable elements, sulphur and phosphorus, are not affected by refining hence cause the furnaceman no concern. The oxidation of the carbon, manganese and silicon is but little different from the oxidation of these same elements in basic practice. By means of the oxygen introduced as rust or scale on the scrap or later as ore or scale into the molten bath, the silicon and manganese are oxidized and go into the slag as manganese silicate. Some iron as silicate likewise finds its way into the slag. The carbon is oxidized to carbon monoxide and escapes as a gas.

Therefore, in taking up the chemistry of the acid process, it will not be necessary to dwell any longer on the oxidation and removal of these three elements because we have learned in a previous chapter (Chap. VII) the procedure whereby these three elements are eliminated either in melting or soon after the bath is molten.

The acid process has, however, two characteristics that warrant viewing in detail. They are: (1) The reduction of the silica in the slag to silicon and the action of this element on the metal and (2) the composition and characteristics of the acid slag. To comprehend the acid process these two characteristics must be thoroughly understood.

The Reduction of Silica to Silicon.—The essentials for the reduction of silica (SiO_2) to silicon are carbon and a high temperature.¹ In the acid open hearth there is usually sufficient silicon reduction to have .08 to .10 per cent in the metal when refining is completed. From this it is quite evident that in the electric furnace where the temperature is much higher the reduction of silica to silicon will proceed much more rapidly. This is the case and unless temperature conditions in the furnace are controlled closely too much silica will be reduced to silicon and the resulting steel will contain more than the desired amount. Thus the temperature of the molten bath is, as we saw in the previous section, kept as low as possible during refining, being increased only in the last few minutes.

¹ A high percentage of acid (SiO_2) in the slag will result in some silicon reduction to restore the equilibrium. This is another cause of silicon reduction.

The majority of metallurgists are convinced that the reduction of silica to silicon which is going on to a slight extent at least, all during refining (this is especially true in the vicinity of the electrodes where the slag is always very hot) is of great benefit in deoxidizing and degasifying the bath preliminary to the final silicon and the manganese addition. They are also pretty well convinced that silicon reduction is a factor of prime importance in the superior properties exhibited by much acid steel. One or two of them have gone so far as to say that the deoxidizing and degasifying powers of silicon reduced from silica are greater and more effective than the deoxidizing and degasifying powers of silicon added as the ferro-alloy. Whether this last statement is true or not, it can be stated with a good deal of assurance that silicon reduction and resulting continual deoxidation is in a large measure responsible for the superior properties exhibited by acid open-hearth steel over the same material made in the basic open-hearth furnace. This, of course, does not hold for acid and basic electric steel (we will discuss this in the next section) but the same principle holds good, namely, that silicon reduction is of great benefit to the final properties of the steel.

The continued reduction of silicon which goes on rapidly if the temperature is sufficiently high, is a source of some annoyance to the furnace melter, unless he has a well-standardized practice. Under varying furnace conditions, a variable amount will be reduced and will go into the steel. It even happens occasionally that the reduction goes too far and the finished steel contains more than is required (.30 per cent or less in acid steel for castings). Even when the temperature of refining is kept low, frequently the heat will need no further addition of silicon before tap.

Preliminary Composition of the Acid Slag.—The acid slag is a complex iron-manganese-silicate or, if some lime has been used in the slag, a complex calcium-iron-manganese silicate. The composition immediately after melting is 50 to 55 per cent silica, SiO_2 , and 45 to 50 per cent iron oxide, FeO , plus manganese oxide, MnO . As soon as the slag is formed it adjusts itself to a definite degree of acidity which remains constant throughout the rest of the heat. The silicates of iron and manganese, especially the former, are strongly oxidizing, thus as first formed the slag is strongly oxidizing.

If, immediately after melting the acid slag is high in bases ($\text{FeO} + \text{MnO}$), due to a high percentage of manganese in the scrap and too much oxidation in melting, silica will be fluxed from the lining to restore the equilibrium. If the slag is too high in acids (SiO_2) due to corrosion of the hearth or lining or to dirt on the scrap some silica will be reduced to silicon and the slag relieved of some of the excess acid.

If the charge was clean and not too high in manganese, but little slag should be formed by the time melting is complete. What little is floating on the metal at this stage should be thin to allow the ready escape of carbon monoxide gas when the carbon is oxidized. If the slag is too thick it may be thinned by scattering a little powdered ore or scale over its surface.

Deoxidizing the Slag.—After the charge is melted and the carbon removed to a point some 3 to 5 points above the required percentage in the finished steel the slag is then deoxidized. It should be clearly understood at this point that deoxidation in the acid-lined furnace is only relative. It never becomes absolute as is possible with a basic lining and carbide slag. The most that can be accomplished in the acid furnace is the lowering of the iron oxide percentage to the lowest point consistent with practical operating conditions.

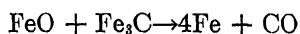
Iron oxide cannot be reduced from an acid slag by maintaining reducing conditions. The only thing possible is to substitute a stronger base for the FeO using for this stronger base a material that will form a non-oxidizing silicate. This material is lime. Sufficient lime to combine with all of the silica cannot be used; in fact we cannot even approach the maximum, as calcium silicate, CaSiO_3 , has a strongly corrosive effect on the acid refractories. It is necessary therefore to deoxidize the slag as much as possible but still keep the percentage of calcium silicate down to the point where it is not excessively harmful. As we cannot reduce the iron oxide content altogether by lime we therefore increase the manganese oxide content and thus substitute a constituent that although oxidizing in itself is of more benefit to the metal than iron oxide. By adding a little powdered ferromanganese¹ to the slag the percentage of MnO may be increased at the expense of the iron oxide. Then by adding lime we decrease the iron oxide content still further and thus decrease the oxidizing powers of the slag.

¹ Many shops use manganese ore for this purpose.

When melted the slag contains approximately 50 per cent silica, 25 to 30 per cent iron oxide, and about 20 per cent manganese oxide. By gradual deoxidation as outlined above the manganese oxide content is increased from 20 to about 25 per cent; a calcium oxide percentage of approximately 10 is added to the slag and the FeO reduced thereby to 15 per cent or below.

As the percentage of iron oxide in the slag decreases the color of the slag becomes lighter. As formed the slag is a brownish black; when the FeO content is about 22 per cent it is light brown, when about 18 to 20 per cent it is a light yellowish brown or a greenish yellow if the manganese oxide is high. When the iron oxide has been reduced to about 15 per cent the slag becomes gray or greenish gray.

Preliminary Deoxidation of the Metal.—The preliminary deoxidation of the metal is by carbon. After the taping down is complete the carbon is some 3 to 5 points higher than is required. At this point the bath also contains dissolved FeO. The amount of this impurity varies; we do not know how much is present; but we do assume that it is in direct proportion and is in equilibrium with the iron oxide in the slag. As we reduce the FeO content of the slag there is a migration from metal to slag to restore the disturbed equilibrium. Therefore some ferrous oxide removal from the molten bath takes place in this way. In addition there is the deoxidation by carbon. Ferrous oxide and carbon (as iron carbide, Fe_3C) cannot exist side by side at steel-making temperatures. They immediately react according to the reaction



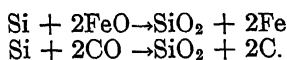
thus there is some deoxidation by the carbon left in the bath. This deoxidation is sufficient to cause a gradual lowering of the carbon percentage in the final refining period.¹ The lowering of the carbon varies with the amount of oxidation, with the amount of ore added, and with the amount of oxidation of the slag. In general it is 2 to 5 points in the final 30 min.

Final Deoxidation of the Metal.—There is also some deoxidation by silicon reduced from silica in the slag. This energetic deoxidizer is also an efficient degasifier, in fact its degasifying powers are more pronounced than its ability to deoxidize. If

¹ This should be contrasted with basic practice where the carbon is apt to increase slightly in the deoxidation period.

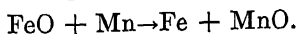
there is not sufficient deoxidation accomplished by the slag, by the carbon and by the reduced silicon, some ferrosilicon may be added. This is followed by the final deoxidizer, ferromanganese.

In the addition of the ferromanganese lies one of the secrets of making good acid steel. The silicon should be added first, well before tap and should, in every case, be followed by manganese. The reason for this is: Silica is the predominating constituent in the acid slag. Therefore the slag has no affinity for the reaction product silica, formed by the reaction of ferrous oxide or carbon monoxide and silicon:

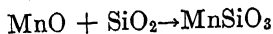


The silica formed will tend to remain entrapped in the body of the molten metal in an emulsified state and will thus form one source of non-metallic inclusions.

Although the deoxidation by the slag, by carbon, and by reduced silicon might be called complete as is shown by some of the silicon going into the body of the metal, there is still some ferrous oxide dissolved which, due to mass action, has escaped reduction by the silicon; because sufficient excess of silicon was not reduced from the slag to overcome the effects of this action. If manganese is now added just before tap the large excess of this deoxidizer will be sufficient to complete the deoxidation according to the reaction



With manganese oxide, MnO, and silica, SiO₂, both present in the bath the tendency to form manganese silicate is great so the following reaction proceeds in the interval between the manganese addition and the final pouring of the steel:



The reaction product, manganese silicate, is liquid at the temperature of the metal, and as such tends to coalesce into sizeable masses and through its lighter specific gravity rises to the top to join the slag. Thus we see that the formation of manganese silicate through the addition of ferromanganese last is the desirable condition to attain; this compound, in contrast to silica, SiO₂, which is solid at bath temperatures, is liquid, of low specific gravity and thus readily removable by gravity from the body of the metal.

It must be admitted that most melters add the manganese first. This is followed by the ferrosilicon, if this alloy is used at all, added to the furnace or to the ladle. This order of adding these two alloys is followed in basic furnace operation and is correct under basic slag conditions. The opposite method should be used in acid practice.

Even though the melter reserves his silicon addition for the last step, he is really getting some of the benefits of an earlier silicon addition, as he has, inherent in his process, the reduction of silicon from silica in his slag. It is because of this early silicon reduction, much stronger in the electric furnace than in the acid open-hearth, that acid steel may be thoroughly sound and free from inclusions even though the manganese addition is made first.

Summary of the Chemistry of the Acid Process.—It is advisable to summarize the foregoing discussion of the chemistry of the acid process with special attention to the chemistry of deoxidation. The steps involved in the chemistry of making a heat of acid electric steel are as follows:

(1) The charge is melted with a minimum of oxidation. The silicon in the scrap is eliminated entirely by the time melting is complete; the manganese is eliminated more or less completely; and the carbon removed to some extent.

(2) The slag, after melting is complete, is a complex iron-manganese silicate containing about 55 per cent silica and 45 per cent iron and manganese oxides. This degree of relative acidity and basicity remains constant during the balance of the heat.

(3) If the carbon, after melting, is too high, sufficient iron oxide in the form of ore or scale is added in small doses to reduce it to the desired amount. This desired amount is a percentage that, after a little is lost through the reactions of deoxidation, and after the final manganese addition is made, will be in the limits required by the finished product.

(4) The slag is then deoxidized. This takes place in two steps: (a) By means of a little powdered ferromanganese the percentage of manganese oxide is increased and (b) by means of lime, calcium silicate is formed. These two steps are sufficient to reduce the percentage of ferrous oxide from 25 to about 15, sometimes even lower.

(5) The decrease in ferrous oxide in the slag disturbs the equilibrium between the ferrous oxide in the bath and the ferrous oxide in the slag and produces a partial deoxidation of the steel by a migration of FeO from bath to slag to restore the disturbed equilibrium.

(6) Deoxidation is further accomplished by the action of the carbon in the bath upon the ferrous oxide dissolved in the metal. The effect of this action is to reduce the carbon percentage slightly. The reaction liberates carbon monoxide gas, most of which escapes; some however remains entrapped in the metal to be later removed by the silicon and manganese additions.

(7) Due to the heat of the arc and to carbon in the metal some of the silica in the slag is reduced to silicon. This silicon migrates into the metal and aids in the deoxidation and degasification. If this silicon reduction is not sufficient to leave .15 to .30 per cent of the element in the steel ferrosilicon is added.

(8) Just before tap sufficient ferromanganese is added to result in a percentage equal to that required in the finished steel. Five to fifteen per cent are allowed for loss. The manganese that is oxidized seeks out any oxidized silica remaining in the metal, to form manganese silicate, which because of its low melting point coalesces quickly and through its low specific gravity rises to join the slag.

(9) Although the acid slag contains 25 to 40 per cent oxidizing constituents ($\text{FeO} + \text{MnO}$); if we lower the ferrous oxide percentage to the lowest possible point and take advantage of the benefits manganese may have on the steel; we may by these two factors bring the ill effects of the oxidizing slag down to a minimum and thus produce sound steel.

ACID VERSUS BASIC ELECTRIC STEEL

In closing this chapter it is desirable that we take the opportunity to view the advantages and disadvantages of the acid and the basic process. Both are well entrenched in the steel industry of this country. Both have many advantages; both have their disadvantages as well. They both have enthusiastic champions; the advocates of one are often somewhat prejudiced against the other. It is necessary therefore that in comparing the two we make every effort to be perfectly fair. From the results of his own experience and from the opinions of others experienced in both acid and basic electric furnace practice

the author has arrived at the following conclusions: (A) Basic practice is best:

(1) For the usual run of plain carbon and alloy steel ingots made in lots of 3 to 40 tons.

(2) For steels of unusual or special analysis in lots of any size from 1 to 40 tons, including high-speed steel.

(3) Where sulphur and phosphorus must be low, *i.e.*, each below .030 per cent.

(4) Where the chemical composition must be confined to a very close range.

(5) Where the low surface tension and easy friability of the basic deoxidizing slag will not influence the quality of the product.

(6) Where a large daily tonnage per furnace is not of prime importance.

(7) Where a low cost is not as essential as a steel completely freed of oxidation defects and gases.

(B) Acid practice is best:

(1) For light, fast work in the foundry, especially for small castings (200 lb. or less).

(2) Where high production and economy of operation is of first importance. Acid operation gives better power consumption (about 10 per cent better). Also the cost of refractories is much lower.

(3) Where little or no refining is necessary.

(4) Where very slow sulphur and phosphorus are not important and where a steady supply of good scrap is assured.

(5) Where the range of carbon, manganese and silicon in the finished steel is comparatively wide.

(6) Where the property of high surface tension of the acid slag is of importance.

(7) If alloy steels are not a daily product.

Now, having compared in a general way, the relative economic and operating advantages of acid and basic practice we will take up this comparison in more detail.

The Lining and Charge in Acid and Basic Practice.—The lining of the basic furnace is by far the most expensive. Likewise it is also the least satisfactory. We have seen in a previous chapter (Chapter II) in just what way acid refractories are superior to basic refractories. It will not be necessary to review this here. In addition magnesite brick cost many times what silica brick cost, and as raw magnesite is, in most cases, imported,

American furnacemen are not assured of a steady uninterrupted supply. The general superiority and lower cost of the acid lining over the basic is unquestioned and is one great advantage in favor of acid furnace practice.

In regard to scrap, basic furnace practice is ordinarily assumed to have a great advantage over acid in that sulphur and phosphorus are removed by basic slags and thus cheaper scrap of lower grade than that necessary for acid practice may be used. While this is theoretically true; practically, the American furnaceman cannot produce as good steel from poor scrap as he can from good scrap, other things being equal. In fact, as we have repeatedly emphasized in an earlier part of this book, to produce high-grade electric steel the charge must be melted without, or at most, with partial oxidation. We have also seen that the phosphorus in the charge should not be over .040 or .050 per cent unless complete oxidation is used. Thus it follows that with the exception of sulphur which, in the basic process is removed automatically, the chemical composition of the charge should be about the same in both acid and basic practice.

A clean scrap is desirable in either practice. Although a dirty, rusty material can be used in both acid and basic practice, it is preferable and results in a better product if the scrap is clean and free from excessive dirt, rust or scale.

We may conclude therefore, that, although the acid process requires scrap a little better chemically and physically than basic, the difference is not sufficient to throw the balance strongly in favor of the basic-lined furnace.

Melting and Oxidizing in Acid and Basic Practice.—In both acid and basic practice the charge is melted as fast as possible and excessive oxidation prevented if high-grade steels are to be made. Both processes remove all of the silicon, most of the manganese and a variable amount of carbon in melting. In addition the basic slag removes phosphorus to a greater or less extent. This is, of course, an overwhelming advantage if very low phosphorus steels are to be made.

Neither process has any advantage in melting or oxidizing as far as time is concerned. In the basic process, however, 20 to 30 min. sometimes more, is necessary to remove the oxidizing slag. This time is saved in acid practice as only one slag is used.

Refining in Acid and Basic Practice.—The basic slag removes sulphur, the acid slag does not. This in itself is sufficient to

throw the balance of favor to the basic furnace if high-grade alloy and tool steels are to be made. In fact, total and positive desulphurization is accomplished by no steel-making operation except the basic electric process. This advantage cannot be overestimated and is one of the chief reasons why the basic process is preferred by makers of fine steels. The phosphorus content in the scrap may be more or less controlled. The basic open hearth produces an enormous tonnage of low phosphorus steel much of which will eventually be turned back into melting scrap. Present open-hearth steels are on an average somewhat higher in sulphur than in phosphorus. A removal of sulphur gives the basic electric process its greatest advantage.

In the final period in the basic process the melter exercises absolute control over the carbon, silicon and manganese. In the acid process these elements cannot be held to such close limits, hence the basic process has a great advantage when special steels are made and when narrow chemical limits are imposed.

From the above statements of the amount of refining it is evident that basic practice must need more time in the refining period. In the acid furnace a heat may be completed and tapped in 20 or 30 min. after the heat is melted. Refining seldom takes more than an hour. On the contrary in basic practice $1\frac{1}{2}$ to 2 hr. is the least time that a heat can be held under a carbide slag and still called finished. Often 2 to 3 hr. under the final slag are required. Hence we see that the basic process has a great advantage in the refining of the metal and in meeting close chemical specifications but that the time required for refining is from two to four times that necessary in the acid heat.

Deoxidation in Acid and Basic Practice.—In deoxidation the arguments are overwhelmingly in favor of basic practice. The carbide slag deoxidizes positively and completely. By deoxidizing with a strongly carbide slag and final degasification by silicon, a heat of steel made in a basic electric furnace should be as sound, dense and free from non-metallic inclusions and gas, as is possible to produce by any steel-making operation.

In the acid process deoxidation is not nearly as complete. The slag is more or less oxidizing all through the heat; deoxidation must, therefore, be accomplished by deoxidizing agents. While these agents, ferromanganese and ferrosilicon, should deoxidize and degasify completely, in many cases they are not 100 per cent efficient. In addition, if there is no deoxidation by the

slag, much more must be accomplished by the ferro-alloys, and as a result, the chances of complete deoxidation and degasification are much less. Likewise the opportunity for the bath being freed of non-metallic reaction products is much greater in the basic than in the acid process. Opposed to the advantage of a more thorough and complete deoxidation by the carbide slag in the basic process, is the continued reduction of the silica in the slag to silicon and the resulting deoxidation and degasification by this element in the acid process.

An advantage of the acid process that we have emphasized in the present chapter is the high surface tension of the acid slag. Disintegration and resulting emulsification of the acid slag is much more difficult than in basic practice, consequently should any slag become mechanically intermixed with the metal in tapping or pouring it will separate and rise to the top much more rapidly and completely if it is acid in character.

Conclusion.—The author has attempted in the present section to present as fairly as possible and without undue enthusiasm either one way or the other, the relative advantages and disadvantages of both acid and basic electric furnace practice. They both have their special fields. Although basic electric steel should, theoretically, be much better than the acid product; actually, much excellent acid steel is made, equal and in some instances superior to the average basic product. Acid furnace practice, on account of the rapidity, economy, and simplicity of its operation has become firmly entrenched in the steel foundry and probably will remain the best process for castings production for some time.

The acid furnace is neither suitable nor efficient in comparatively large units and is consequently seldom used for ingots. Here the basic process because of its refining and deoxidation features is undoubtedly the best. The desulphurizing ability of the carbide slag and the possibility of producing a metal free from excessive segregation and free from non-metallic inclusions and gas has served to place the basic electric process in the front rank as a producer of fine steel.

Regardless of whether an acid or basic lining and slag are used, the electric process because of its flexibility and because of its ability to produce a high-grade product is, without doubt, the coming practice for fine steel production in the ferro-metallurgical industries.

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